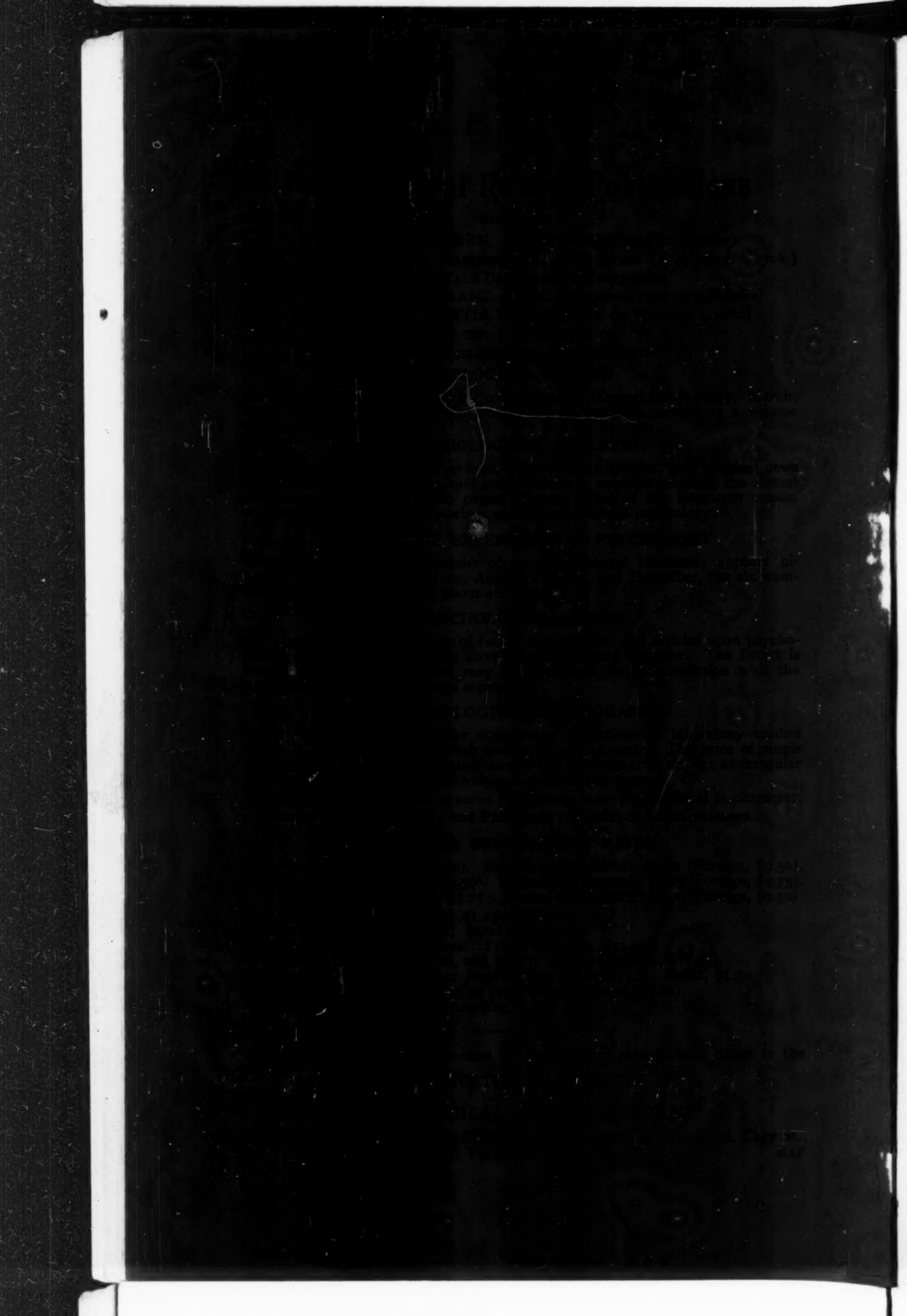

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THE INFLUENCE OF VISUAL GUIDANCE IN MAZE LEARNING

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For this experiment, a new type of stylus maze was constructed of such a character that the correct path and the cul de sacs can not be distinguished from each other by means of vision. The grooves for the stylus were milled as represented by the cross section diagram of Fig. 1. The stylus

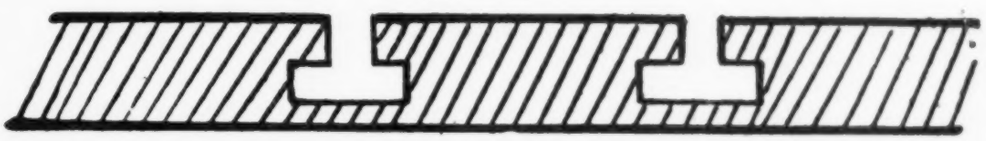

FIG. 1. Cross section of maze representing two grooves.

consisted of a hard rubber handle at one end of which was attached by a ball and socket joint a circular metal disc of such dimensions that it moved very easily through the lower part of the groove. The pattern of the maze is represented by the diagram of Fig. 2. Its dimensions are 16 x 16½ in. The starting point is located at *A*, while position *B* is the goal or objective of each trial. The stylus is inserted in the groove at *A*, and the entrance is then blocked by a sliding metal strip. The stylus can not now be removed from the maze until position *B* is reached, where it may be easily lifted from the groove and again be inserted at *A* for the succeeding trial. So far as vision is concerned, all possible paths from *A* lead to the goal at *B*, while as a matter of fact all paths, with one exception, are blocked by invisible stops whose

positions are represented by the short lines drawn across the grooves. With the aid of these lines, the course of the true path and the positions of the blind alleys are readily apparent

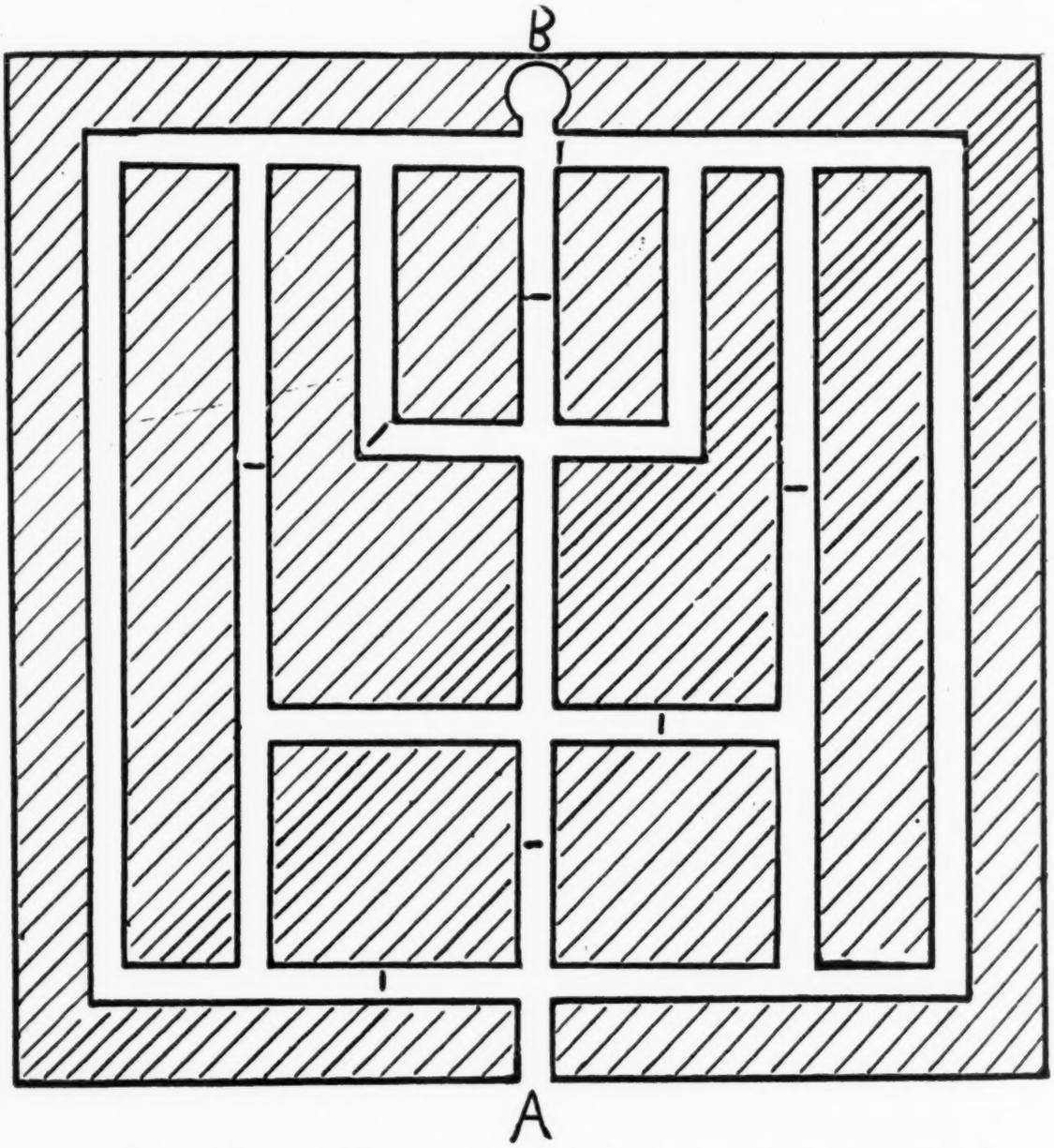

FIG. 2. Diagram of maze pattern. Lines drawn across the grooves represent the positions of the invisible stops.

to the reader. These stops project out in the lower part of the groove a sufficient distance to prevent the passage of the stylus disc, but not far enough to be visible to the subject.

The essential feature of this type of maze is the fact that the stops are invisible. As a consequence, the subject is unable to distinguish between the true path and the cul de sacs by means of vision. The maze may thus be learned in whole or part with the coöperation of visual perception, or it may be mastered in the usual manner by excluding vision by means of an intervening screen.

1. *Varying Amounts of Initial Visual Guidance.*—Six groups of subjects were employed in the first experiment. Group I. was permitted one minute for a visual inspection of the maze with instructions to obtain all the aid possible for its subsequent mastery. At the end of the period, the screen was placed in position and the maze was mastered with vision excluded. Group II. was permitted the use of vision during the first trial, and the mastery of the maze was then completed without vision. Groups III., IV., and V. were likewise allowed the use of their eyes during the initial 2, 3, and 5 trials respectively, and the learning was then completed without the aid of vision. These records are to be compared with those of Group VI. that learned the maze entirely without the coöperation of sight. This group will be termed the normal. In all cases, the maze was learned by a series of successive trials.

The comparative data are given in Table I. The first column lists the groups and the conditions of learning. In the second column is given the number of subjects employed in each group. Following are the average trial and error records for the various groups. These are total values and they include the records for both the guided and the unguided trials. The last two columns represent the influence of the visual control as measured in terms of the normal record. The positive values indicate the percentages of saving due to vision, while the negative values represent its detrimental influence. The group given five trials with vision completed the mastery of the maze with an additional 5.5 trials. As compared with the normal records, this amount of guidance was effective in producing a saving of 46.1 percent in trials and 80.9 percent in errors.

TABLE I

INFLUENCE OF INITIAL VISUAL GUIDANCE

Group	Number	Trials	Errors	Percentages of Saving	
				Tr.	Er.
I. Inspection	6	28.0	143.0	−43.6	28.8
II. 1 trial	12	20.4	86.7	− 4.6	56.9
III. 2 trials	12	19.0	95.0	2.5	52.8
IV. 3 trials	11	11.0	30.5	43.6	84.9
V. 5 trials	12	10.5	38.6	46.1	80.9
VI. Normal	11	19.5	201.2	——	——

The one-minute period of visual inspection of the maze exerted a detrimental effect upon the mastery of the problem when measured in terms of trials. It exerted a beneficial effect upon the error record, reducing the number of errors per subject by 28.8 percent in spite of the increase in the number of trials.

One and two trials with vision were approximately equal in effectiveness. They exerted no appreciable influence upon the total number of trials necessary to learn the maze, but these amounts of guidance were effective in decreasing the number of errors by over 50 percent.

Three and five trials with vision are apparently equal in effectiveness. They decreased the number of trials by at least 40 percent and the number of errors by 80 percent.

Three and five trials with vision are much more effective than either one or two trials. Obviously the effectiveness of visual guidance is not proportional to its amount. One and two trials with vision exert a much more favorable effect than does one minute of visual inspection. This amount of time devoted to visual inspection is approximately the same as that secured when vision is permitted during the first trial.

In all cases, the visual control is much more effective in preventing and eliminating errors than in reducing the number of trials.

Vision operates to prevent error not only during the trials in which its use is permitted, but also during the post-visual

period of learning. The relative effectiveness of the control during the visual and post-visual stages of learning may be determined from the data of Table II. The second column gives the total error decrease during the trials in which vision was permitted. These values indicate the effectiveness of vision in preventing error in absolute terms. The third column states the average decrease per trial during the visual period. The fourth column gives the total decrease relative to the corresponding normal record in percentage terms. Vision operated to prevent 90 percent of the normal amount of error during the first three trials. The same values for the post-visual period are given in columns 5, 6, and 7 respectively.

TABLE II

ERROR DECREASE DURING VISUAL AND POST-VISUAL PERIODS

Group	Visual Period			Post-visual Period		
	Total	Ave.	Percent	Total	Ave.	Percent
II. 1 trial.....	27.3	27.3	70	87.2	4.5	54
III. 2 trials.....	74.0	37.0	80	32.2	1.9	30
IV. 3 trials.....	104.4	34.8	90	66.3	8.3	77
V. 5 trials.....	122.2	24.4	86	40.4	6.5	68

Visual perception is extremely effective in preventing and eliminating error. When vision is permitted for one to five trials, the normal error record is decreased by 70 to 90 percent. The total number of errors prevented is not proportional to the number of trials. This result is due to the fact that the normal error curve falls very rapidly during the early trials. Stated in relative or percentage terms, the effectiveness of vision increases up to the third trial. The decreased value for five trials is due to the fact that with visual guidance practically all errors have been eliminated by this time.

There is no definite relation between the amount of visual guidance and the total saving of errors in the post-visual period. This fact may be accounted for in several ways. The post-visual periods differ considerably in length. With

three and five trials of guidance, a fewer number of trials are required to learn the problem (Table I.). With these amounts of guidance, the post-visual period begins at a later stage in the mastery of the problem. When but one guided run is permitted, its post-visual effects are exerted at a time when normally many errors are being made. Measured in terms of total errors saved, any factor will be more effective in the initial stage of learning than during the final runs when the mastery of the maze is practically completed.

The influence of differences of length of the post-visual period may be eliminated by comparing the four amounts of guidance in terms of the average saving per trial. A comparison in terms of the percentage of saving will eliminate the influence of differences of position. It is apparent that the post-visual effectiveness of guidance is not proportional to its amount when measured in average or percentage values. As in the case of trials, however, three and five guided runs are considerably more effective than one or two.

Measured in relative terms, the immediate effect of guidance is invariably much greater than its subsequent effect upon the post-visual stage of learning.

Similar results were obtained from a study of the error curves whose graphs are not given. The curves for the guided groups start at a considerably lower level and fall at a somewhat faster rate than that of the standard group. With the removal of the guidance, the curves immediately rise and then descend in an orderly manner. The post-visual effect of two guided runs is confined to five trials. The curve remains below that of the normal from the third to the eighth trial, and from this point on the two are practically identical. The post-visual effect of one guided run is more prolonged. Its curve remains below the level of the normal up to the eighteenth trial. The post-visual curves for three and five guided runs are quite similar. They consistently maintain a lower level than those of the groups given one and two guided trials. In general, three and five guided runs exert the most effect upon the post-visual stage of learning, while the least effect was exhibited by the guidance given for two trials.

The immediate effect of the guidance upon the error score is easy to explain. Its effects are to be explained in part in terms of visual perception and in part in terms of a memory of these visual data. Vision permitted the subject to locate the goal and make more systematic explorations in the attempt to reach it. After traversing a certain distance in the maze, vision enabled the subject to foresee that certain paths could not lead to the goal and as a consequence certain cul de sacs were never entered. Vision enabled the subjects to identify the blind alleys more readily. Without vision, a person may enter and emerge from a short cul de sac without any knowledge of its character. Vision reduced very materially the amount of retracing over the true path, and the number of entrances into a given cul de sac during any trial. Some retracing did occur occasionally. Subjects sometimes retraced in order to explore certain paths which had been previously passed without being entered. Even with vision a subject may become lost during the first trial and retrace as a consequence. The memory factor is apparently quite effective in reducing the number of errors in the succeeding trials.

There are two ways in which vision may be effective in the post-visual period. We may assume the retention of some memory of the visual appearance of the maze pattern and its subsequent utilization as a guiding factor. The second conception assumes that the act is learned in tactual and kinæsthetic terms. Visual perception is directly effective in preventing error and thus aiding the development of a more perfect tactual motor coördination, and it is this more highly perfected act which is carried over into the post-visual period. Subjects, who have been permitted the use of vision, enter the post-visual period at a more advanced stage in the learning process than do those persons to whom vision was denied. On this assumption, the groups given guidance will be able to complete the mastery of the problem with less time and effort than the normal group.

Both conceptions are plausible. They are not mutually exclusive alternatives and both may be true. No facts were

obtained which prove or disprove the second assumption. Several lines of evidence support the validity of the first hypothesis.

Visual inspection of the maze enabled the subjects to localize the goal and obtain some notion of the size and character of its pattern. This preliminary visual experience did not, however, permit any differentiation between the true and false paths. The effects of this inspection were retained and it exerted some influence upon the process of learning. Its influence upon trials was detrimental, but the total error record was decreased by 28.8 percent and the average number of errors per trial by 50 percent. The facts prove rather conclusively that a memory knowledge of the visual features of the maze can be utilized as a guiding factor.

The fact that the effectiveness of the visual control is not proportional to its amount can not be explained wholly on the basis of the tactual motor hypothesis. According to this conception, visual inspection should exert no effect, five guided runs should be more effective than three, and two trials more effective than one. The fact can be explained in terms of a memory of the visual data. Both detrimental and beneficial effects will result from an inadequate and partially incorrect notion of the appearance of the maze pattern. The beneficial effects will increase as the guiding concept becomes more definite and precise, and the maximal amount of benefit will be obtained from that amount of guidance necessary to develop a correct conception of the maze pattern. As a matter of fact, the maze was visually mastered at the end of the third trial by the majority of the subjects. Of the first two groups, but one of the twenty-four subjects obtained a visual mastery of the maze within two trials. When three guided trials were given, seven subjects were able to identify the correct path by sight. With five guided runs, seven subjects mastered the problem in terms of vision by the end of the third trial, and three others by the end of the fifth trial. The average number of trials necessary to learn this maze in visual terms is probably somewhere between

three and four. Since a correct notion of the maze pattern is attained in about three trials, any additional visual experience will be without effect.

The effectiveness of the memory factor was indicated by the remarks of the subjects. Its efficacy apparently varied with the individual. Some asserted that they retained an adequate memory of the appearance of the maze pattern and that the few errors made were due to carelessness. This type of subject traversed the maze slowly and carefully and made the best records. Some subjects exhibited a certain degree of uncertainty and indecision at the beginning of the first trial without vision. These people asserted that this uncertainty was due to the lack of any adequate memory of the visual path. Others did fairly well on the first trial but exhibited considerable hesitation at the beginning of the second trial. These subjects ascribed this hesitation to the fact that the appearance of the maze had been forgotten in the meantime. In other cases the subjects proceeded confidently until difficulties were encountered, and these mistakes were usually attributed to a wrong visual conception. A few subjects reported that this memory control was detrimental inasmuch as they discovered after several trials that they could do better by relying exclusively upon kinæsthetic clues for guidance.

After the maze was mastered without the use of vision, all groups were required to run it for several trials when vision was not excluded. All subjects in the groups given three and five trials of visual guidance made no errors in this test. Evidently these subjects had developed a correct notion of the appearance of the maze pathway, or their movements were guided wholly in kinæsthetic terms. In the two trial group, two subjects made one error each which they ascribed to an incorrect idea of the nature of the path. In the one trial group, one subject had developed a very erroneous concept of the maze as a visual object and as a consequence made twenty-two errors in his first attempt to traverse the maze with the use of vision. One error was made in the second

attempt, but the third was successful. Vision was now excluded and four errors resulted. Evidently the correction of the visual control had disturbed the kinæsthetic coördination. Three of the six subjects who had been given one minute for a preliminary inspection of the maze pattern made slight mistakes when attempting to traverse it with perceptual guidance. The test was also given to the group that learned the maze entirely without the aid of vision. These subjects invariably reported that the maze pattern looked very much different from what they had anticipated. Two individuals made slight mistakes which were apparently due to the fact that the introduction of vision increased speed. Two other subjects made errors because they were guided in part by vision.

TABLE III

INFLUENCE OF POSITION OF GUIDANCE

Group	Guidance	Total Saved				Percentage Saved			
		Tr.	Err.	V.	P.V.	Tr.	Err.	V.	P.V.
III. 12.....	1–2	.5	106.2	74.0	32.2	2.5	52.8	80	29
VII. 10.....	5–6	3.3	53.4	16.7	36.7	17.0	21.0	75	67
VIII. 12.....	9–10	− .5	17.2	.2	17.0	− 2.5	8.5	3	46

2. *Position of Visual Guidance.*—Two trials of visual guidance were introduced at different stages in the learning process. Group III. was permitted to utilize vision during the first two trials and was then required to master the maze without this aid. Group VII. ran the first four trials without vision. Visual guidance was then introduced during the fifth and sixth trials, and after this the mastery of the maze was completed with vision excluded. With group VIII., the visual guidance was introduced during the ninth and tenth trials. The comparative data are given in Table III. The results are stated in terms of the effects of the guidance relative to the records of group VI. that mastered the maze entirely without the aid of vision. Group VII. consisted of 10 subjects. Guidance was given during the fifth and sixth

trials. This group learned the problem in 3.3 fewer trials than did the normal, and made 53.4 fewer errors in so doing. Of these errors, 16.7 were saved during the period of guidance and 36.7 during the post-visual period of mastery. The values in the last four columns represent the same data stated in terms of percentages. For example, the saving of 16.7 errors which occurred during the two guided runs is 75 percent of the error record of the normal group for the corresponding trials.

Visual guidance introduced in the initial or final stages of learning exerts no appreciable effect upon the number of trials required to master the maze. Two guided runs in these positions are no more effective than an equal number of unguided trials. When two trials of visual guidance are inserted in the intermediate position, they exert a greater effect than a similar number of unguided trials.

Visual guidance for all positions is much more effective upon errors than trials. The earlier the introduction of vision, the greater is its effect upon the total error score.

Guidance in all cases is effective upon errors during both the visual and the post-visual stages of learning.

Considering the *immediate* effect of visual guidance upon errors, it is evident that the earlier its introduction, the greater is its effect when measured either in absolute or percentage terms. For the initial position, vision reduced the error score for all subjects. In the intermediate position, vision was effective only with those subjects who had made but little progress in error elimination. The introduction of vision in the final position was slightly effective with a few subjects, not effective with the majority of the individuals, and detrimental with two subjects. This distractive effect was apparently due to the fact that these individuals had developed an erroneous notion of the visual appearance of the true pathway, and consequently became confused and lost when vision was introduced.

The effect of vision during the post-visual period is greatest for the intermediate position when measured in terms of the

total errors saved, the average saving per trial, and the percentage of saving. The initial position is more effective than the final position in respect to the total and average number of errors saved. Measured in terms of the percentage of saving, guidance in the final position is the more effective. The saving resulting from visual guidance in the initial position is confined to the first five trials of the post-visual period. Guidance in the other positions manifests an effect throughout the post-visual period. The post-visual efficacy of guidance apparently varied with the individual. Guidance in the initial position was quite effective with some subjects and detrimental with others. When introduced in the intermediate position, guidance was effective in all cases. The efficacy of the control for the final position was confined to a few individuals.

No generalization can be made as to the most advantageous position in which to introduce a visual perceptual control. It is possible that more advantageous results might have been secured by the introduction of vision during the third and fourth trials. Moreover, the most effective position may vary with the amount of guidance given. The character of the problem may also be a conditioning factor.

3. *Influence of Indirect Visual Guidance.*—A final experiment tested the influence of indirect visual guidance by the use of map diagrams representing various features of the maze pattern. These diagrams were exact duplicates of the maze as to size. They were placed on the table at the left of the screened maze. The nature of these maps was explained to the subject and he was instructed to utilize the diagram in guiding his movements through the hidden maze.

Group IX. mastered the maze with the use of map *A*. This diagram represented all the possible pathways but it did not enable the subject to distinguish between the true path and the cul de sacs. It represented the maze pattern as it appeared to vision. Group X. learned the maze with the aid of map *B* which is represented in Fig. 2. This diagram was like that of map *A* with the single exception that

the positions of the various stops were indicated by lines drawn across the pathways. These lines enabled the subjects to distinguish between the cul de sacs and the true path. Group XI. utilized map *C* which represented the course of the true path. The subject was informed that the maze contained numerous cul de sacs but that these were not represented in the diagram. The comparative data of these groups are given in Table IV. in addition to the records of the normal group that mastered the maze without the aid of vision.

TABLE IV

INFLUENCE OF INDIRECT VISUAL GUIDANCE

Group	Number	Total Trials	Initial Errors	Total Errors	Percentage of Saving	
					Trials	Errors
VI. Normal.....	12	19.8	54.1	201.2		
IX. Map *A*.....	11	11.8	47.5	105.4	40	48
X. Map *B*.....	11	7.5	3.7	14.7	62	93
XI. Map *C*.....	11	14.5	5.2	31.2	27	84

All three modes of indirect visual guidance were extremely effective in reducing both the number of trials and the amount of error requisite to the mastery of the problem. In all cases the controlling factor was more effective upon errors than trials.

The effectiveness of the guidance upon trials and errors was proportional to the amount of knowledge obtained from the diagram. Diagram *B* was the most effective, and obviously it gives the most information concerning the maze. Likewise, more information can be derived from diagram *C* than from map *A*.

There is no evidence that map *A* was effective in reducing the number of errors during the first trial. The difference between this value and that of the normal group may be accounted for in terms of chance. Moreover, this form of guidance was about equally effective upon both trials and errors. The error curve for this group begins approximately at the same height as that of the normal group, but it drops

very much more rapidly. This form of guidance exerts its main effect after the subject acquires some notion of the maze pattern during the initial trial.

Diagrams *B* and *C* were very effective during the first trial. The initial error records of these two groups were 3.7 and 5.2 respectively. The two curves maintain a similar relation to each other throughout the mastery of the problem. Both forms of guidance were very much more effective upon errors than trials.

The initial influence of these modes of indirect guidance may be compared with the direct effect of vision. The average error record for the initial trial of the four groups that were permitted the use of vision was 11.7. These conditions were like those obtaining for the group that utilized map *A*, with the single exception that the guidance was introduced directly in the one case and indirectly in the other. Direct guidance is the more effective not only during the initial run but throughout the learning process. The indirect guidance exerted by diagrams *B* and *C*, however, is more effective during the first trial than is the direct influence of visual perception.

With map *A*, the subjects were required at the end of each trial to identify the course of the true path in terms of the diagram. At no time were the subjects informed as to the correctness of these judgments. The learning process with this mode of guidance may thus be divided into two stages,—the initial period during which the pathway is being visually identified, and the final stage of completing the mastery of the problem. The records for the two periods of learning are given in Table V.

TABLE V

TWO STAGES OF LEARNING WITH THE USE OF MAP *A*

	Trials	Initial Error	Total Error	Average Error
Initial period	3.8	47.5	92.0	24.2
Final period	8.0	2.0	13.4	1.7

The first identification was incorrect with each subject. Three of the eleven subjects were successful after the second run. The average number of trials required by the group to master the maze in visual terms was 3.8, and the average error record per trial for this period was 24.2.

A visual mastery of the maze did not enable the subjects to traverse it without error. Eight additional trials were required. Individuals differ in their ability to guide their movements by a visual diagram. Two subjects were able to run the maze correctly as soon as they succeeded in identifying the pathway on the map. A third subject made 2 errors in his first attempt but was successful thereafter. A majority of the individuals required a considerable number of trials to complete the mastery of the problem. Few errors, however, were made in the final period. Of the 88 trials occurring during this period, an error score greater than 3 occurred in but three runs. The errors were slight but difficult to eliminate.

Similar results obtained with the use of map *B* which enabled the subjects to identify the course of the true path before attempting to run it. One subject was able to traverse it successfully on his first attempt, while another subject mastered the problem in one trial. Other individuals manifested considerable difficulty in guiding their movements by means of the diagram, but in all cases very few errors were made in any trial.

The subject's confidence in his identification was in general proportional to its correctness. The first confident judgment was invariably correct, and with the exception of one subject a correct identification was never subsequently revised. This individual correctly and confidently identified the true path at the end of the third trial. This judgment persisted for the fourth and fifth runs, and a wrong path was then chosen at the end of the sixth trial. The subject reverted to his previous correct choice on the next trial. This judgment was again revised after the ninth run and this wrong conception persisted until the problem was completely learned. We have

here the anomalous case of the development of the proper kinæsthetic motor coördination under the supervision of a wrong visual conception. The record of this subject, however, was not unusual in other respects. His trial and error scores were somewhat above the average for the group. Poorer scores were made by other individuals, and the deviation from the group average may well be accounted for in terms of chance. His error of identification was slight, however. When required to run the maze with the aid of direct vision, this individual made but one error in his first attempt.

During the initial period, the subject acquires two factors which are potentially significant for the subsequent mastery of the problem. The correct identification of the true pathway on the diagram is one. The second factor is the kinæsthetic motor coördination which has been developed during these trials. The relative value of the two factors may be determined from a comparison of the records for the final period with those obtained by the group that used map *B* as a guide. Group IX. learned to identify the true path on map *A* after 3.8 trials. Group X. was furnished this means of identification by map *B*. Group X. thus began the problem at a point comparable with that attained by group IX. upon entering upon the final period of mastery. Any difference in the two records must be due to the influence of the kinæsthetic-motor tendencies which were developed during the initial period. The comparative data are given in Table VI.

TABLE VI

INFLUENCE OF VISUAL IDENTIFICATION OF THE TRUE PATH

	Trials	Initial Error	Total Error	Average Error
Map *A*, final period.....	8.0	2.0	13.0	1.7
Map *B*.....	7.5	3.7	14.7	1.9

The two sets of records are practically identical in every respect. We are thus forced to conclude that the motor activity involved in running the maze during the initial period

was primarily valuable on account of its visual consequences. Presumably certain kinæsthetic motor tendencies were also acquired, but apparently these tendencies must have exerted both detrimental and beneficial effects upon the subsequent process of learning.

After the problem was learned, certain subjects were required to run the maze without the use of the diagram. Five individuals of group IX. were subjected to the test. Two ran the maze perfectly for several successive trials, one made a slight error in his first attempt, while two experienced some difficulty for several trials. Ten subjects of group X. were tested. Six ran the maze perfectly. Three made a few errors for several trials, while one individual experienced considerable difficulty in mastering this new phase of the problem. He required 12 trials and made 17 errors in learning to adjust to the new situation, as compared with 13 trials and 30 errors in learning to run the maze with the aid of the diagram. Evidently individuals differ very materially in their reliance upon the perceptual control after the problem is learned. The ability to run the maze without the aid of the diagram was apparently not correlated with the number of trials required to learn the problem. In this connection it was noticed that several subjects dispensed with the perceptual use of the diagram when the problem was about half mastered. In response to inquiries they replied that they preferred to rely upon a memory of the diagram as a control. Others reported that it made no difference whether they perceived or remembered the diagram in the later stages of learning. On the other hand, some individuals felt that the perceptual means of control was essential to a good record.

When the diagram was removed after the problem was mastered, the maze was traversed in terms of kinæsthesis or by means of a memory of the diagram. We have no decisive data upon which to base an estimate as to the relative importance of the two factors. Individuals differed in their subjective estimates of the importance of the memory factor, but such reports can not be taken seriously.

4. *Influence of a Visual Control derived from Kinæsthetic Data.*—Although any visual perceptual contact with the maze was denied the normal group, it must not be supposed that all modes of visual guidance were excluded. Under these conditions, subjects do gradually construct from their unseen movements some sort of an idea of the visual appearance of the true path. It is reasonable to suppose that this conceptual schema as it develops operates in turn to influence the succeeding attempts at traversing the maze, for our previous experiments have indicated the effectiveness of such concepts when derived from visual perceptual data.

The question as to the influence of such a control can be answered by a comparative study of the records of blind and normal subjects. I am indebted to Miss Helen Koch for the data given in Table VII. which were obtained with the use of a different maze from that employed in our experiments. The normal group consisted of ten college students. The table gives their average scores in trials, total errors and total time, in addition to the poorest record obtained for each of these three measures. The three subjects with defective vision were also college students. Subject *A* was able to see shadow differences in the visual world. Subjects *B* and *C* have been totally blind from birth. Subject *B* was a Phi Beta Kappa student, and subject *C* was able to enter the Law School after graduation from college. The records were obtained during their undergraduate work.

TABLE VII

COMPARISON OF NORMAL AND BLIND SUBJECTS

	Trials	Total Errors	Total Seconds
Normal average	44.3 ± 21.8	325 ± 197	1,466 ± 766
Poorest normal score	97	740	4,112
Subject *A*	46	566	1,731
Subject *B*	92	2,705	9,595
Subject *C*	83	3,671	7,291

There is no conclusive evidence that the ability of subject *A* was limited by his visual defect. His record in every case

was less than the poorest normal score. While his values were greater than the corresponding normal averages, yet in only one case do they exceed the average range of normal variability.

The totally blind subjects were evidently at some disadvantage in mastering such an act of skill. Their scores for trials exceed the average range of normal variability, but lie within the maximal range. Both the error and time values, however, lie far beyond the maximal range of normal variability. The error records are four to five times larger than the poorest normal score, while the time values are about twice that of the largest normal record. The visual deficiency of these subjects has certainly affected their time and error records, and possibly it has influenced their trial scores to a slight extent.

More comparative data are necessary for any confident generalizations. Moreover, it is somewhat of an assumption to maintain that the totally blind subjects were at a disadvantage primarily for the lack of a capacity for visualization. Granted the assumption, however, it is to be noted that the results confirm our former conclusions that the indirect mode of visual control is much more effective in reducing errors than trials.

Our experiments have been concerned with a general problem of considerable theoretical and practical importance, viz., the significance of the visual processes in the acquisition and performance of various acts of skill. As a general rule, both the direct and indirect participation of vision in these activities has been largely ignored. It has been the usual custom to describe such activities wholly in tactual and kinæsthetic terms. Our results at least indicate the probability that the visual modes of control are much more effective in the acquisition and performance of acts of skill than hitherto suspected.

SMALLER VS. LARGER UNITS IN LEARNING THE MAZE

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University of Idaho

Investigation has raised a doubt in the minds of some[1] concerning the validity of the statement that to 'learn by wholes rather than by parts' [2] is the more efficient method. Whenever such experimental results have been presented the investigator has attempted an explanation of why learning by smaller units should be found more efficient as a learning means.

Continued investigation with respect to this matter seems to give stronger and stronger evidence that for maze learning (motor learning) [3] the smaller unit methods are not a little, but are very much, better as learning means than is the case for very large ones.[4] Similar results are being found for other forms of learning.

The data for this study were obtained during the second semester of the school year 1920–21. The subjects used were members of one of the psychology classes made up of six males and twenty-eight females. These subjects were assigned to the various method-groups by chance selection. The 'whole method' group was made up of 2 males and 10 females, the 'part continuous method' group of 2 males and

[1] Peckstein, L. A., 'Whole Versus Part Method in Learning Nonsensical Syllables,' *Jr. Ed. Psychology*, 1918, p. 387.

[2] Starch, Daniel, *Educational Psychology*, 1921, p. 185.

[3] Possibly all learning is motor and that the different types indicated by most writers are only evidences of the specific nature of the nerves involved in the respective aspects of adjustment.

[4] I appreciate the uncertainty of meaning attached to the words 'whole' and 'part' in discussions on learning. I suppose no one doubts that a unit of practice might be made too large for adequate learning for any individual in any field of study. No one can mean such a 'whole' as this in such discussion, but just what is meant has been defined for each particular case as it has come up.

9 females, and the 'part method' group of 2 males and 9 females.

For this study the meaning assigned for each of the three methods used is as follows: By the 'whole method' is meant that the learners always started at the entrance of the maze and continued in their random efforts until they reached the end of the complete maze. This was repeated in each case until the maze was learned. By the 'part continuous method' is meant that such learners began always at the entrance of the maze but first finished at the end of the first quarter. After this quarter was learned the second quarter was added to the first and these two together served as the second unit. When these two were learned the third quarter was added to the first two. When this three-quarter-unit was learned the last quarter was added. Then the whole maze was taken as a unit and completed. By the 'part method' the learners learned each quarter separately in regular order. After each one had been so learned they were combined into a single unit and relearned as a whole.

Each individual of the various groups was required to come each day at a designated time, for a period of fifteen minutes, until the learning had been completed. This was not always complied with, but the irregularities were pretty well distributed throughout. The room in which the work was done was the same for all subjects, and the position of the subjects and the experimenter in the room was rather constant. On a few occasions a subject was required to use a different room, but as far as the groups were concerned there was no difference in treatment in any matter except as the nature of the experiment required. Two of the subjects in the 'part method' group dropped out of school before finishing the experiment.

The intelligence of the various subjects, as measured by the Otis Group Scale, and the college grades for the school year 1920–21 are shown for each group by Tables I., II. and III.:

Tables Showing Results of Otis Tests and the Average School Marks for the Year 1920–21

Table I

Whole Method Learners

Subjects	School Marks	Score in Each of Ten Tests										Totals
		1	2	3	4	5	6	7	8	9	10	
I.....	5.162	10	21	22	17	16	14	18	11	22	25	176
II.....	5.470	14	25	21	18	16	12	19	16	24	21	186
III.....	3.527	12	15	4	11	5	6	8	11	17	12	101
IV.....	5.805	16	22	21	20	16	13	18	5	23	21	175
V.....	4.416	13	17	12	14	15	9	15	10	18	22	145
VI.....	5.214	11	16	10	11	15	10	12	11	23	19	138
VII.....	5.243	11	20	19	18	16	13	13	10	18	21	159
VIII.....	5.405	12	18	18	18	12	10	13	3	20	26	150
IX.....	5.089	9	18	14	16	12	10	13	10	18	21	141
X.....	5.176	12	16	6	19	8	7	7	8	24	19	126
XI.....	5.400	14	22	18	9	16	11	15	15	12	24	157
XII.....	5.342	10	18	17	12	12	13	15	11	23	25	156

Table II

Part Continuous Learners

Subjects	School Marks	Score in Each of the Ten Tests										Totals
		1	2	3	4	5	6	7	8	9	10	
I.....	5.314	12	20	17	17	15	14	18	11	23	24	171
II.....	3.875	12	19	18	12	14	10	18	15	21	24	163
III.....	4.393	14	17	21	18	18	8	9	16	24	17	162
IV.....	3.880	14	20	24	19	18	11	19	16	21	25	187
V.....	5.242	14	14	13	17	7	9	10	8	15	22	129
VI.....	5.171	12	15	14	19	17	10	14	13	18	22	154
VII.....	5.114	13	20	18	17	16	12	16	18	22	20	162
VIII.....	4.800	13	17	16	15	15	11	11	10	24	21	153
IX.....	4.566	..	..	..	..	..	..	..	..	..	..	...
X.....	3.111	9	15	22	15	10	7	8	6	23	20	135
XI.....	3.500	..	..	..	..	..	..	..	..	..	..	...

The materials used in this experiment were first a maze made up of a board 20″ x 15″ x 1″ on which were nailed cleats of board one inch wide and three-eighths inch thick in such way as to leave a groove about three-eighths inch wide. There were 31 cul de sacs ranging in length from one to four and one fourth inches and a true path of exit making a com-

TABLE III

PART LEARNERS

Subjects	School Marks	Score in Each of the Tests										Totals
		1	2	3	4	5	6	7	8	9	10	
I.....	5.200	11	17	16	19	15	10	16	13	22	18	157
II.....	5.218	11	19	15	19	16	13	17	7	22	16	155
III.....	5.192	13	20	19	11	15	12	13	15	15	24	157
IV.....	3.807	12	18	23	16	10	9	14	11	17	19	141
V.....	5.550	13	16	20	17	13	12	14	11	25	24	165
VI.....	5.542	13	16	16	18	15	12	16	9	19	19	153
VII.....	4.617	10	17	7	8	14	8	9	4	22	20	129
VIII.....	5.459	9	16	16	17	11	4	15	11	21	23	143
IX.....	4.334	13	21	16	18	13	11	9	10	16	16	143

plete length of 107 inches. Through this groove of cul de sacs and true path the subject was required to trace from the entrance to the end of the groove, by means of a penholder, turned top end down, while he sat blindfolded on the opposite side of a table from the experimenter.

The maze was numbered every inch or so for purposes of keeping a record of just what part of it was of greatest difficulty. The experimenter kept a complete record of the number of errors, the place of error on the maze, the number of trials, and the time. A stop watch was used in recording the time.

A trial is a tracing from the start to the end of a designated unit. This means that the trials were longer for the larger-unit learners. The 'whole' learners had the possible maximum length of trial each time, the 'part continuous' learners had a trial the length of which became greater as the quarters were added, and the 'part' learners had the shortest trials, for a unit in this case consisted of only one fourth of the maze at a time until the fourths were combined. At this point the latter group had a trial equal in length to the 'whole' learners. The whole-maze unit, or any other unit, was considered learned when the subject succeeded in going through it three times in succession without error.

In no case was a learner permitted to see the maze until after it had been completely learned. Many of them knew nothing about the location of the end of the unit to be learned, how large the maze was, or whether they were to walk around in it or not. Some of the last ones to work on the experiment had been talked to by the ones finishing earlier, but the three groups shared about equally in this.

The instructions that were given to the subject, in each case, on beginning the experiment for the 'whole' learners were as follows: "On the reverse side of this board narrow strips of wood are nailed so as to leave a space between them. This space is made so that it is a continuous groove with many blind alleys branching from it. Your problem is to trace through this continuous groove by means of a pen handle. There is only one possible way out. A mistake is made when you go into a blind alley and then have to retrace to get out, or when you retrace a certain distance in the true path toward the beginning. A blind alley never has more than three turns in it. You will continue at the work until you can trace through the maze three consecutive times without error."

"You will continue this work fifteen minutes each day until you have completed it. Have you any questions?"

The instructions for the 'part continuous' and for the 'part' learners were the same as for the 'whole' learners, except that there were changes made to let them know how the ends of the smaller units were to be indicated. In all cases of tracing through a unit the hand of the subject was guided back to the start by the experimenter for the beginning of a new trial. Whenever a subject would retrace to the start the experimenter so signified by saying, 'start.'

Below are tables which show the number of trials, the number of errors and the time in seconds for each subject of the respective groups as well as the average for each item of measurement:

The tables for the 'part' learners and the one for the 'part continuous' learners show figures in the column of trials that are inclosed in parentheses. These are included because they

Tables Showing Number of Trials, Number of Errors and Time in Seconds

Table IV

Part Continuous Learners

Subjects	Trials	Errors	Time
I	109	364	5,520
II	73	227	4,645
III	194	1,491	6,825
IV	130	577	5,315
V	72	389	3,305
VI	83	378	3,435
VII	90	408	3,445
VIII	86	1,228	4,770
IX	84	397	5,185
X	168	568	6,015
XI	73	548	4,380
Average	105.6(52.8)	597.7	4,803.6

Table V

Whole Learners

Subjects	Trials	Errors	Time
I	30	609	3,770
II	103	1,726	6,535
III	37	992	3,863
IV	46	1,461	5,565
V	39	673	4,825
VI	35	687	3,360
VII	49	887	4,815
VIII	53	712	5,360
IX	98	1,666	5,110
X	32	1,066	4,055
XI	79	1,753	5,685
XII	39	1,189	6,670
Average	53.3	1,118.4	4,976.5

indicate more correctly the true averages for trials, if they are to be directly compared with such results for the 'whole' learners. A trial for the 'part' learners was only one fourth as long as was the case for the 'whole' learners for most of the learning practice. The trials for the 'part continuous' learners were very much shorter in the same way, except that there were more attempts at the whole maze in this method of practice than was the case for the 'part' learners.

Table VI

Part Learners

Subjects	Trials	Errors	Time
I	97	399	3,405
II	131	373	5,060
III	63	692	4,390
IV	39	349	2,810
V	81	531	3,735
VI	72	323	3,700
VII	85	436	3,290
VIII	97	358	2,840
IX	132	836	3,715
X	...	...	....
XI	...	...	....
Average	88.6(22.15)	477.2	3,660.5

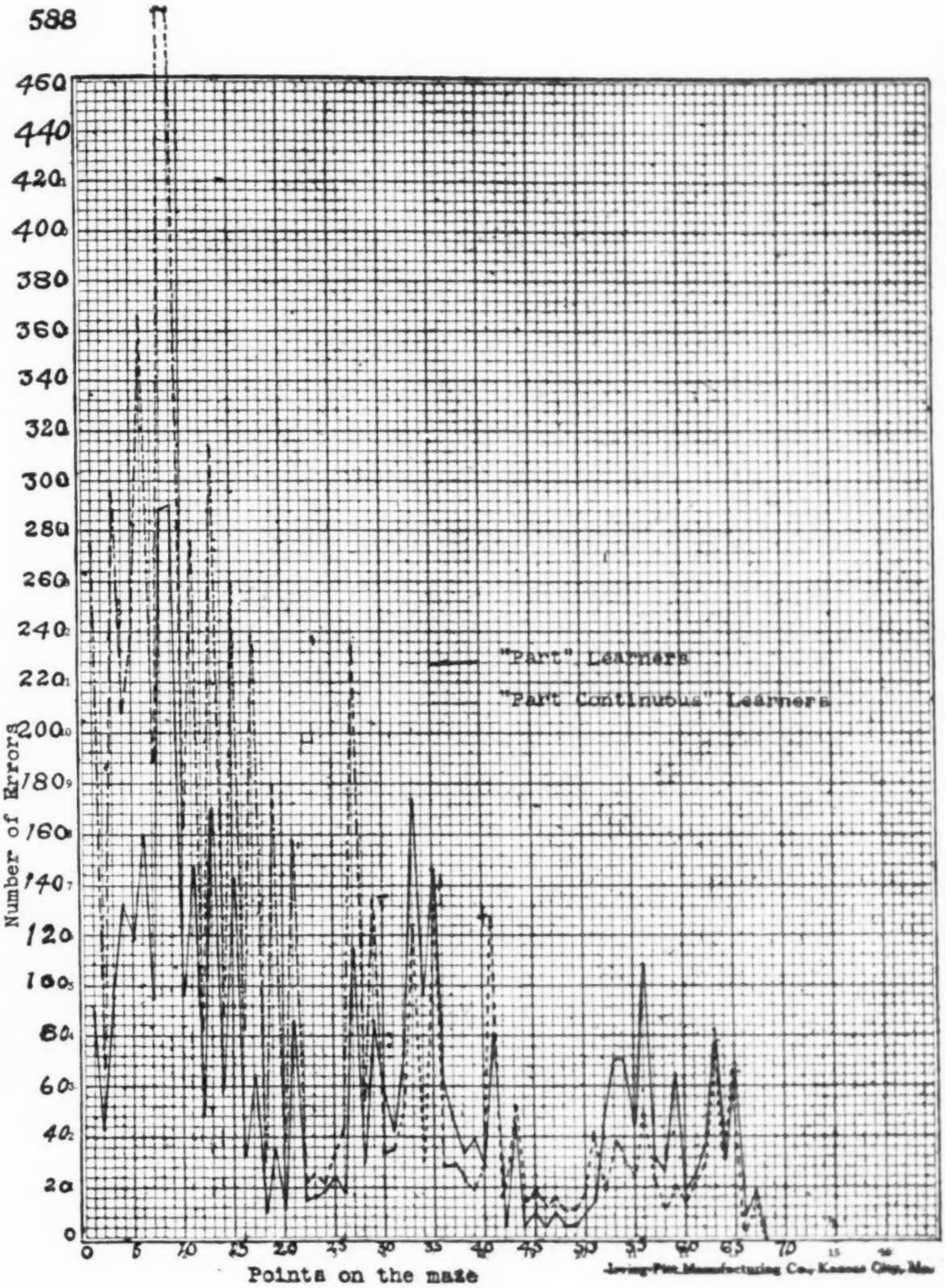
Other aspects of learning are presented by Tables VII. and VIII. and the curves that follow. These show the number of errors for each of the quarters of the maze used in this experiment. These data indicate what the case is here for such matters as 'transfer,' 'backward elimination,' and repetition as factors conditioning learning. Such material is of use in explaining why a given method proves nore effective as a learning means.

Average Number of Errors by Quarters for Each Method

Table VII

Method	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
Whole	352.6	167.4	87.4	71.5
Part Continuous	386.9	112.8	54.8	43.2
Part	231.4	109.4	59.8	82.8
Totals	972.9	389.6	202.0	197.5

If the data presented in Table VII. is presented in the form of the per cent. that each other quarter is of the fourth


588
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Number of Errors
"Part" Learners
"Part Continuous" Learners
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Points on the maze
Ivins-Pitt Manufacturing Co., Kansas City, Mo.

quarter, in the number of errors made, we get the figures given in Table VIII. below:

TABLE VIII

Method	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
Whole	493.2%	233.8%	123.4%	100%
Part Continuous	896.0%	261.0%	126.9%	100%
Part	279.2%	123.8%	72.2%	100%

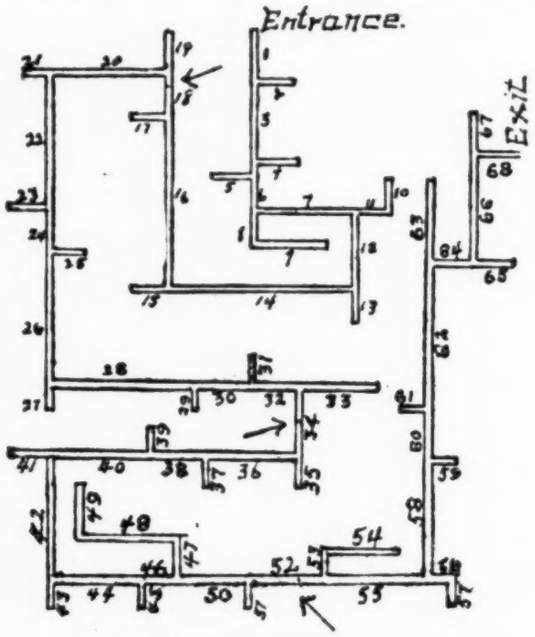


DIAGRAM OF MAZE

The arrow indicates the ends of the quarters.
A small wooden plug was inserted at these points.

Tables IV., V. and VI. show very plainly that for errors the '*part method*' *is very superior as a learning means*, for this exercise, when compared with the 'whole method' results. There is a gain of 57.3 per cent. in this aspect of learning when using the smaller units. The 'part continuous method' shows a gain of 46.5 per cent. over the 'whole method' as a learning method in the number of errors made.

In the matter of time, the gain over the 'whole method' is not so pronounced—it being 26.4 per cent. for the 'part method' and 3.4 per cent. for the 'part continuous.' When what was said above concerning the number of trials is considered, it will be seen that the gain for either of the 'part

methods' over the 'whole method' is very considerable in all three particulars.

These differences in performance in this experiment can not be explained on the basis of difference in mentality for the three groups, for the 'whole' learners have higher school marks than either of the other two groups. In the mental tests the 'whole' learners came second in mentality as measured by this test. The 'part' learners, as a group, was the lowest of all. The differences for the Otis Tests were so slight, however, that they can not be considered as significant. We must look elsewhere for an explanation of the superiority shown by the 'part' learners in this study.

There is evidence of very great 'transfer' if Tables VII. and VIII. are observed. Here we find a gradual improvement in learning for each succeeding quarter in all three methods except for the case of the fourth quarter in the 'part method' figures. In this single case the third quarter was less difficult by 27.8 per cent. than the fourth quarter.

This evidence of transfer should be expected, for the parts of the maze are very much alike. This similarity in parts *involves much the same nerve processes* in the impulse phenomena required in the responses had in successfully reaching the end of the unit of learning used. By looking at the diagram of the maze it will be seen that the last quarter is less like the others than any other one.

What has been said about the 'positional establishments' [1] when the units are being connected, as an explanation of the waste in 'part' learning can have no point in this experiment; because the 'part method' is, by far, the best of the three methods here used. There is no waste to be explained and the 'negative transfer' [2] is not found except in going from the third to the last quarter. The loss here could likely be explained on the basis of the maze difference indicated above. Such a difference as this necessarily involves a greater dif-

[1] Peckstein, L. A., 'Alleged Elements of Waste in Learning a Motor Problem by the "Part" Method,' *Jr. Ed. Psychology*, 1917, p. 309.

[2] *Ibid.*, p. 306.

ference in *nerve functionings* than that found for the other three quarters.

Either of the 'part methods' shows advantages over the 'whole method.'[3] This was the case in this experiment even though the connections of the smaller units were not attempted until after each of the four quarters had been learned as isolated processes. This advantage is likely explained, partially at least, on the transfer basis.

Transfer seems to be best taken care of when *there is identity of neural factors involved* in the two or more situations of response; provided that these neural factors are most *ready to respond* at the different times and in the different situations of stimulation. This readiness seems to be best provided for *by the needs of the being* for organization required in response. The organization is determined by the nature and the nurture of the subject used. What is presented at any point in the accumulation, to be effectual, *must involve neural elements already utilized in this organized accumulation;* for it appears that each being is a unity at any time, however poorly directed some might seem. Learning then likely means organization in neural bond relations for response plus the tendency to act on occasion of stimulation. The stimulation situation must be of a size that will best bring into function all the matters of readiness as well as those of identity in neural units used if the transfer effects are to reach the maximum for adequate learning.

It is not shown that the parts used, in the most adequate learning of this maze, were just the proper size to obtain the best results. It is a 'lucky strike' if they are of the optimum length. The size of unit to use, for the best results in transfer, is that which involves neural factors most widely used in units to be learned subsequently; provided that it is not too large to get the maximum helps from the readiness for response factors. To make it too large is to overwhelm the

[3] Peckstein, L. A., 'Whole Versus Part Method in Learning Nonsensical Syllables,' *Jr. Ed. Psychology*, 1918, p. 386.

learner and thus prevent the adoption of the new impulse phenomena into the ever-accumulating organization.

It might be found that there is an *optimum size of unit for each kind of material to be learned*, and again it might be the case that the size of the unit should differ for each individual learner. Subject No. 6 used only 3,360 seconds in learning the whole maze by the use of the 'whole method.' This is better than any other learner regardless of the method used, except for cases No. 4, No. 8, No. 7 of the 'part learning' group. Other such individual differences within each group are shown, as well as much overlapping from group to group. Such evidence seems to imply that a general rule with respect to the size of unit to use in verbatim learning is going to be hard to define.

Notwithstanding these apparent discrepancies there seems to be ample evidence to justify the doubt that has been raised in the minds of some concerning the validity of the statement that to 'learn by wholes rather than by parts is more efficient.' [1]

[1] We have gathered data on nonsense learning and on the memorizing of prose and poetry which is being put in form for publication. While it is a little early to determine positively as to the superiority of the methods used, the indications seem to avor some form or other of the 'part method' as being the more efficient.

IMPROVED FORMS OF STEADINESS TESTER AND TAPPING PLATE

BY KNIGHT DUNLAP

The Johns Hopkins University

I. Adjustable Steadiness Tester

The form of steadiness tester illustrated in Fig. 1 has been in use in several departments of the Johns Hopkins University, and in other institutions, for several years, and has proved its value. The holes of graded sizes are arranged in a circle in a brass disc, which is placed in front of a second disc of the same size, having a single hole slightly larger than the largest hole in the first disc. The first disc turns on the short brass rod to which the second disc is fastened, so that any of the test holes can be brought over the single hole in the second disc. Two brass springs fastened to the second disc, and rubbing on the first disc, furnish friction sufficient to hold the first disc in any position, and also provide good electric contact between the two discs. By means of a thumbscrew on the rod, the pressure of the springs can be adjusted.

The rod carrying the two discs is held by a combination clamp on a vertical rod, so that the angle between the disc-surface and the line of sight can be varied; the position of the single hole in the second disc can be varied; and the height of the discs can be varied. The cut shows the single hole at the bottom of the fixed disc. When used in this position, we find that adjusting the height so that the center of the disc is always at the height of the reactor's shoulder gives fair comparisons.

The instrument is shown as connected with the 120-volt D. C. power line, with telephone receiver and two 10-watt lamps in series with stylus and plate. By using a lamp in each side of the circuit, no dangerous short-circuit can occur,

although if the connections on the stylus and telephone receiver are not carefully covered, the psychologist or the reactor may receive a shock on touching the test-plate with the bare hand.

The telephone receiver is for most purposes as reliable as any available form of recording apparatus, in spite of the theoretical advantages of the latter. In cases where special study is to be made of the durations of touches, and where other considerations may be sacrificed to this, recording markers may be substituted for the telephone receiver, with appropriate change of current. For such work, a condenser must be used, of course. Dry cells may be used with the telephone receiver; but in that case, the durations of the touches can not be readily noted. 60 cycle, A. C. is even better than D. C. For most purposes, it is sufficient to count the number of touches in the standard time, and to note whether the reactor belongs to the type which readily follows instructions to move the stylus away from the brass immediately on making contact, or belongs to the type which tends to press the stylus against the brass.

The angular adjustment of the plate may be made once for all: we use it tilted upwards 15 degrees from the vertical. The vertical adjustment for each reactor, whether the tests are made in sitting or standing position, is of primary importance, if reactors are to be compared fairly. If it is desired to alternate between sitting and standing positions with a given reactor, two rings, one above and one below the clamp, may be set on the vertical rod in the proper positions, and the plates may then be slipped from the one position to the other without further measurement.

The rotation of the test-plate is also very important. By this means, each hole used is brought into exactly the same position for use, and hence in using a series of holes on one reactor, the arm and eye adjustment may be made identical for the several holes. In the older forms of plate, there are two holes which are adjacent in the series of sizes, but which

lie, one at one end of the top row, and the other at the other end of the bottom row. We have found that the change from one of these holes to the other introduces a decided 'step' in the numbers of touches in the holes in running through the series. Such disturbances are entirely avoided in our test-plate.

The test-plate is six inches in diameter, and has places for 15 holes arranged in a circle of two and three eighths inch radius. In the instruments used so far, only eleven of these holes have been put in, namely: holes of 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 24, sixty-fourths of an inch diameter. This series seems excellently adapted to cover the requirements for work on children and adults; but any other series on either the inch or the millimeter scale may be put in.

The vertical rod which carries the plates is three fourths of an inch in diameter, and 30 inches long, and is mounted on a cast-iron base, designed for this instrument, which allows very convenient placing on any table.

II. Double Tapping Plate

In place of the usual single tapping plate, we are using a double plate, Fig. 2, and are requiring the reactor to strike the stylus alternately on the two plates. In this way, accurate records may be obtained by a make-and-break counter, such as the Ewald chronoscope. (*Some* Ewald chronoscopes will work accurately.) With the single plate, no form of counter yet devised will give accurate counts, and many serious errors may be made with a counter and plate which record fairly well for some reactors, and not for others. With the double plate, the necessary method of stroke gives more reliable contact, and slight oxidization of the plate is less important.

By using a definitely coördinated movement, we not only eliminate tremor-tapping, but also avoid some of the pseudo-practice effects, due to changes of method in holding the stylus, in force of blow, and in force of grip of stylus: changes which come in suddenly in many cases with the single plate.

The plates in this instrument are 3 inches square, separated by a bakelite block 1 inch wide, which rises 3/16ths of an inch above the surface of the plates. This block prevents the reactor from drawing the stylus across the plates. The plates are mounted on a cast-iron base, so heavy that it need not be fastened to the table. The base is hollow, and the condenser is to be placed under it, and connected to binding posts provided on the inside. The use of a condenser prevents the rapid deterioration of the plate surface. The Western Electric 1 microfarad condenser works well.

We are no longer able to undertake the manufacture of either of these instruments, and they will be supplied by Stoelting.

ELIMINATING THE PITFALLS IN SOLVING CORRELATION: A PRINTED CORRELATION FORM

BY HERBERT A. TOOPS

Institute of Educational Research, Teachers College

The time and labor involved in calculating the Pearson r, even when using a plotting method, is great. Then, also, where many individual product-moment multiplications, involving plus and minus signs, have to be made and summated, errors are likely to be numerous. In consequence, the research worker does not employ the method of correlation in many cases where the correlation coefficient, or the regression coefficient, would throw much light on the statistical results of his experiments.

The plotting method outlined below will greatly facilitate the computation of correlation coefficients in point of both economy of time and reduction of the chances for making errors in the computations. By use of this method, the laborious computation of individual product-moments is eliminated; negative deviation steps of other methods are replaced by steps all of which are positive, thus making all summations positive and readily done on the adding machine; there are no corrections, d_y or d_x, to be computed; and a printed table does all required extensions of table step deviations and their squares by their respective frequencies.

Fig. 1 shows in detail the general scheme of the method. This method combines in practical form four principles of use in "short-cut" calculations in solving correlation:

(*a*) When we expand the algebraical expression,[1]

$$\Sigma(X - Y)^2 = \Sigma X^2 - 2\Sigma XY + \Sigma Y^2, \qquad (1)$$

[1] Chapman, J. C., 'A Method of Calculating the Pearson Coefficient of Correlation, without the Use of Deviations or Cross Multiplying,' PSYCH. BULLETIN, Vol. 16, No. 11, 1919, pp. 369–370.

Fig. 1. The Solution of r by Use of the Printed Correlation Form.

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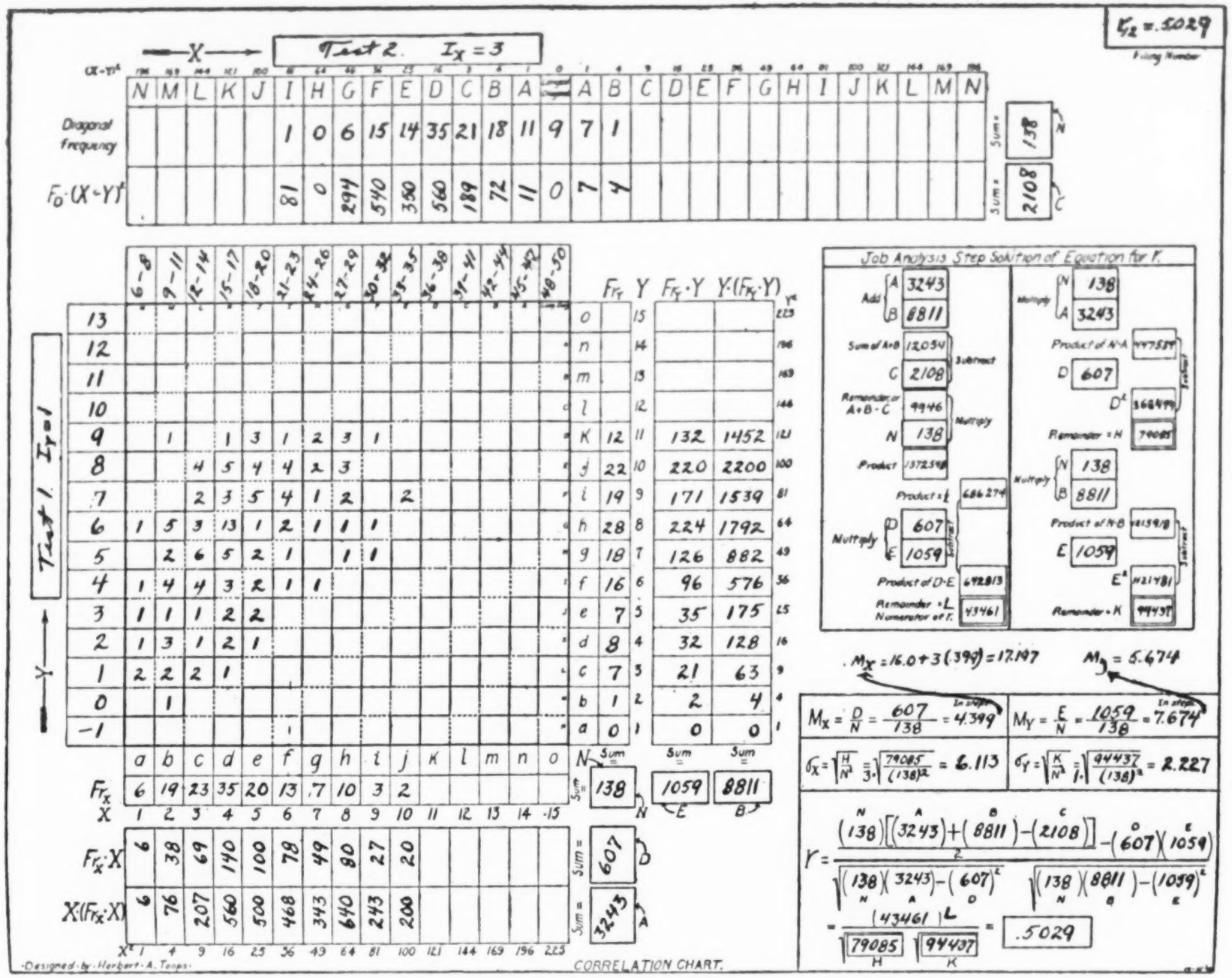
Test 2. $I_X = 3$
Test 1. $I_Y = 1$
X
Y
Diagonal Frequency
$F_D \cdot (X-Y)^2$
F_{rx}
F_{ry}
$F_{rx} \cdot Y$
$Y \cdot (F_{rx} \cdot Y)$
$F_{rx} \cdot X$
$X \cdot (F_{rx} \cdot X)$
$r_{12} = .5029$
Job Analysis Step Solution of Equation for r.
$M_X = 16.0 + 3(.399) = 17.197$
$M_Y = 5.474$
$M_X = \frac{D}{N} = \frac{607}{138} = 4.399$
$M_Y = \frac{E}{N} = \frac{1059}{138} = 7.674$
$\sigma_X = \sqrt{\frac{H}{N^2}} = 3 \cdot \sqrt{\frac{79085}{(138)^2}} = 6.113$
$\sigma_Y = \sqrt{\frac{K}{N^2}} = 1 \cdot \sqrt{\frac{94437}{(138)^2}} = 2.227$
$r = \frac{(138)\left[\frac{(3243)+(8811)-(2108)}{2}\right]-(607)(1059)}{\sqrt{(138)(3243)-(607)^2}\ \sqrt{(138)(8811)-(1059)^2}}$
$= \frac{(43461)}{\sqrt{79085}\ \sqrt{94437}} = .5029$
Designed by Herbert A. Toops
CORRELATION CHART.

FIG. 1. The Solution of r by Use of the Printed Correlation Form.

we find that,

$$\Sigma XY = \frac{(\Sigma X^2 + \Sigma Y^2) - \Sigma(X - Y)^2}{2}. \qquad (2)$$

If the right-hand member of equation (2) is substituted for ΣXY in the equation for r involving gross measures,

$$r = \frac{N \cdot \Sigma XY - \Sigma X \cdot \Sigma Y}{\sqrt{N \cdot \Sigma X^2 - (\Sigma X)^2}\ \sqrt{N \cdot \Sigma Y^2 - (\Sigma Y)^2}}, \qquad (3)$$

a formula results which allows us to substitute the squared terms of equation (2) in place of the laborious product-moment sum, ΣXY.

(*b*) If the average of both distributions is assumed at the zero step, then all step deviations become positive, eliminating all negative step deviations, and the gross measure formula, (3), applies to the step deviations considered as positive gross measures.

(*c*) If X and Y be taken as table steps in a correlation plot, and the $(X - Y)$ differences be plotted by compartments, it will be found that for *any given diagonal row* the $(X - Y)$ differences are all alike; this allows one to *count* the *diagonal frequencies* by rows and then multiply the total diagonal frequency of a given diagonal row by its proper $(X - Y)^2$ to obtain that diagonal row's contribution to $\Sigma(X - Y)^2$ of formula (2). Thus, the simple procedure of counting diagonal frequencies replaces the laborious product-moment computations of other methods.

(*d*) The first power of the table steps, and also the squared terms employed in formula (2), each multiplied by all possible frequencies up to as high as 50, are readily grouped in tabular form on a printed $8\frac{1}{2}$ x 11-inch chart, the use of which, in making extensions of table steps and their squares by frequencies, eliminates the larger part of the labor involved in making such extensions by the usual methods. The adding machine performs all the positive summations and affords

a check when comparing the original entries with the record which the listing-adding machine supplies.

The bearing of these four facts upon the method will be suggested by the formula itself, which is derived by substituting equation (2) in equation (3):

$$r = \frac{\frac{N}{2}[(\Sigma X^2 + \Sigma Y^2) - \Sigma(X - Y)^2] - \Sigma X \cdot \Sigma Y}{\sqrt{N \cdot (\Sigma X^2) - (\Sigma X)^2}\,\sqrt{N \cdot (\Sigma Y^2) - (\Sigma Y)^2}}. \qquad (4)$$

In this formula, X and Y are graph steps, or table deviations; ΣX and ΣY are arithmetical sums of positive quantities. The corrections for an assumed mean become an integral part of the formula and do not have to be calculated separately as in other plotting methods. The formula is quite general and applies to the actual gross measures as well as to the table steps considered as gross measures.

That the $(X - Y)$ differences for any given diagonal row is a constant for every compartment in that diagonal row may be easily proven mathematically. This is shown schematically also in Fig. 2. The equation of the longest diagonal row of compartments is, $Y_0 = X_0$; of the first diagonal row downwards, $Y_1 = (X_1 - 1)$, since this row differs from the preceding diagonal row only by its y-intercept, a constant quantity for the row considered. Generalizing, the equation of the nth diagonal row downwards is, $Y_n = (X_n - n)$. Now for this nth diagonal row, the $(X - Y)$ difference is, $X_n - Y_n = X_n - (X_n - n) = n$, a constant, the ordinal number of the diagonal row below the longest, or main diagonal row. For diagonal rows above the longest diagonal, n is negative in sign but it is squared in formula (2) and so becomes positive in its summation.

Referring to Fig. 1 for illustrations, the itemized procedure in calculating r is as follows:

1. Enter the names of the X- and Y-variables in the proper boxes on the correlation sheet.

2. Enter the classes of the X-variable in ascending order

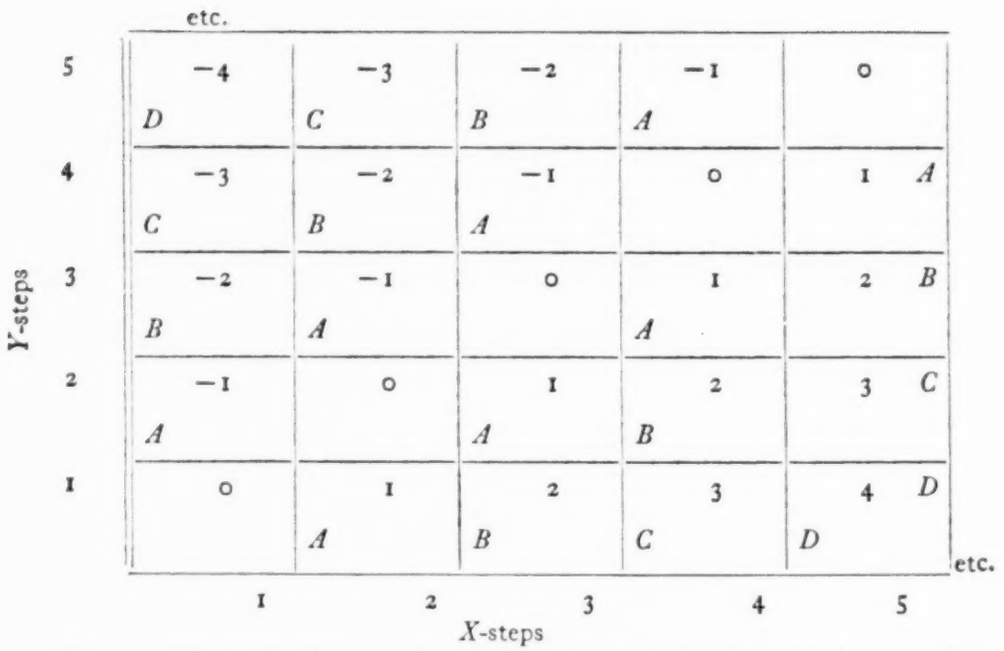

FIG. 2. Schematic diagram showing how the $(X - Y)$ difference for any given diagonal row is a constant, thus allowing the counting of diagonal frequencies to take the place of product-moment multiplications. The quantity in each compartment is the X-step of that compartment minus its Y-step. Since the $(X - Y)$ differences are squared, thus becoming positive, before being used in formula (2), there are no negative signs to be taken into account. The frequencies of a given diagonal row, identified by a small capital letter in Fig. 1, are counted and then multiplied by the positive $(X - Y)^2$ quantity of the diagonal row considered. For the longest diagonal row, $(X - Y)^2$ is zero; for each of the diagonal rows just above and below, each lettered A, $(X - Y)^2$ is 1; for the two rows lettered B, $(X - Y)^2$ is 4; for the two rows lettered C, $(X - Y)^2$ is 9, and so on.

from left to right. Use such class intervals, I_x, that the maximum number of classes will result.[1]

[1] In order to find the class intervals, I_X and I_Y: In the variable under consideration, subtract the lowest gross score obtained from the highest gross score obtained; to the remainder add 1; divide the quantity thus obtained by the maximum number of classes of the printed chart, here 15; the quotient, raised to the *next highest* integer is the correct maximum class interval. Example: The lowest score on a test is 13; the highest, 40. Then the class interval, I_X, is:

$$I_X = \frac{(40 - 13) + 1}{15} = \frac{28}{15},$$

which, when raised to the next highest integer, is 2.

As a desirable convention the first step class should always *begin with a multiple of the class interval;* thus, in the above example, the classes would run (class interval = 2):

Class	Step
12–13	1
14–15	2
16–17	3
Etc.	

3. Enter the classes of the *Y*-variable in ascending order from bottom of the sheet to top.

4. Plot the paired measures as tally marks in the compartments using the classes determined in procedures 2 and 3 as coördinates. When completed, enter the frequencies of each compartment as a small figure in the lower left hand corner of each compartment. (To avoid confusion the tally marks are omitted in Fig. 1 and these compartment frequencies only are shown as a figure in the center of each compartment.)

5. Add vertical frequencies by columns, entering column frequencies at the feet of the proper columns in the row, $Fr._X$.

6. Add horizontal frequencies by rows, entering the row frequencies at the right hand ends of the proper rows in the column, $Fr._Y$.

7. Add the frequencies of the several diagonal rows separately, guided by the dotted lines, and enter the several diagonal row frequencies in the correspondingly lettered spaces provided at the top of the page in the horizontal row, marked, "Diagonal Frequency." (A small capital letter serves to identify the diagonal row; a given diagonal row's total frequency is to be entered under the corresponding large capital letter. Note that *A* means that diagonal row which has an $(X - Y)$ value of ± 1; *B*, an $(X - Y)$ value of ± 2, and so on. Note also that, on this chart, the *N*-diagonal frequency is the sum of the frequencies of but one compartment, *M* of two, *L* of three, and so on. A celluloid stencil or cardboard serrated edge may be helpful in relieving eye strain when counting the diagonal frequencies, and will contribute to accuracy in the counting.)

8. Add all vertical, horizontal, and diagonal marginal frequencies. Each sum must add up to *N*, the total number of cases, in the respective *N*-windows.

9. Multiply the $Fr._X$ frequencies by the respective *X* table steps obtaining the row of products, $Fr._X \cdot X$; likewise multiply the $Fr._Y$ frequencies by the respective *Y* table steps obtaining the column of products, $Fr._Y \cdot Y$.

10. Multiply the X steps respectively by the $Fr._X \cdot X$ products above obtained thus securing the $X \cdot (Fr._X \cdot X)$ products; likewise, multiply the Y steps respectively by the $Fr._Y \cdot Y$ products above obtained thus securing the $Y \cdot (Fr._Y \cdot Y)$ products.

11. Multiply the several diagonal frequencies by their respective $(X - Y)^2$ values, thus obtaining the $F_D \cdot (X - Y)^2$ products.

12. On the adding machine add the products separately of each of the five rows and columns of procedures 9, 10 and 11. In the example, Fig. 1,

$$\begin{aligned}
\Sigma Fr._X \cdot X = \Sigma X &= D = 607 \\
\Sigma Fr._Y \cdot Y = \Sigma Y &= E = 1059 \\
\Sigma X \cdot (Fr._X \cdot X) = \Sigma X^2 &= A = 3243 \\
\Sigma Y \cdot (Fr._Y \cdot Y) = \Sigma Y^2 &= B = 8811 \\
\Sigma F_D \cdot (X - Y)^2 = \Sigma (X - Y)^2 &= C = 2108 \\
&N = 138.
\end{aligned}$$

13. Substitute the values thus found in formula (4) and solve for r. (To facilitate this operation, a skeleton formula is employed. Since the chart is a printed form chart the required six sums always appear in a definite place, the lettered windows as given above, in each case. By substitution of the above-lettered notation for the algebraic notation of formula (4), the skeleton formula in the lower right-hand corner of Fig. 1 results. The substitution of the letter-named window sums in the skeleton formula is a process understood by clerical workers who have no training in the statistical notation which the letters replace.)

It will be readily apparent that Table I., which is complete for only the frequencies 1 to 9 inclusive, in its complete form may be used to do all the extensions of marginal frequencies by the table steps and their squares, and will replace all of the work of procedures 9, 10 and 11 above. Table I. (rows a, b, c, $\cdots$, and rows, a^2, b^2, c^2, $\cdots$) gives for the first nine frequencies, or 1 to 9, the $(X \cdot Fr._X)$, $(X^2 \cdot Fr._X)$, $(Y \cdot Fr._Y)$, and $(Y^2 \cdot Fr._Y)$ values, and also (in rows A, B, C, $\cdots$), the

$(X - Y)^2 \cdot F_D$ values. The author makes use of a larger printed table, $8\frac{1}{2}$ x 11 inches in size, which gives the products by units for all frequencies from 1 up to 50, and by tens from thence on to 100. With two workers,—one to read frequencies and work the adding machine, the other to read the Table I. entries corresponding to the marginal frequencies—the required quantities may be taken from the table almost as fast as they can be placed into the adding machine, since just one figure is taken from each row of the table in succession down the page. The extension of table steps and their squares by frequencies may also be found by using the multipliers printed directly on the chart, as well as from Table I. which uses the a and a^2, b and b^2 letters as guides to locate the table entries in turn. The products, however obtained, may be either written down in the proper spaces of the correlation sheet, or be added directly on the adding machine to obtain the respective sums. In the latter case the adding machine record serves as a check on the accuracy of the original extensions.

A calculating machine is very efficient in reducing the skeleton formula to the final form involving the simplified reductions, L, H and K. This reduced form may then be easily solved by slide rule. The integral quantities, H and K, enter directly into the computation of the standard deviations.

In all operations, two workers are preferable: A, to enter tally marks of paired scores read to him from the original data by B; later, A to read in succession to B the letters and corresponding marginal frequencies, the tabulated products of which are found in Table I. by B; then, finally, A to enter these products on the printed graph sheet while B enters them into the adding machine. Checking may be readily accomplished by A and B interchanging places and checking the products with the printed listed record of the adding machine.

The solution of equation (4) may be simplified, for the benefit of persons not accustomed to the solution of equations,

Table I.

Table of First and Second Powers of Steps by Frequencies

Fr.		1	2	3	4	5	6	7	8	9	Fr.	
	a	1	2	3	4	5	6	7	8	9	a	
A	a^2	1	2	3	4	5	6	7	8	9	a^2	*A*
	b	2	4	6	8	10	12	14	16	18	b	
B	b^2	4	8	12	16	20	24	28	32	36	b^2	*B*
	c	3	6	9	12	15	18	21	24	27	c	
C	c^2	9	18	27	36	45	54	63	72	81	c^2	*C*
	d	4	8	12	16	20	24	28	32	36	d	
D	d^2	16	32	48	64	80	96	112	128	144	d^2	*D*
	e	5	10	15	20	25	30	35	40	45	e	
E	e^2	25	50	75	100	125	150	175	200	225	e^2	*E*
	f	6	12	18	24	30	36	42	48	54	f	
F	f^2	36	72	108	144	180	216	252	288	324	f^2	*F*
	g	7	14	21	28	35	42	49	56	63	g	
G	g^2	49	98	147	196	245	294	343	392	441	g^2	*G*
	h	8	16	24	32	40	48	56	64	72	h	
H	h^2	64	128	192	256	320	384	448	512	576	h^2	*H*
	i	9	18	27	36	45	54	63	72	81	i	
I	i^2	81	162	243	324	405	486	567	648	729	i^2	*I*
	j	10	20	30	40	50	60	70	80	90	j	
J	j^2	100	200	300	400	500	600	700	800	900	j^2	*J*
	k	11	22	33	44	55	66	77	88	99	k	
K	k^2	121	242	363	484	605	726	847	968	1089	k^2	*K*
	l	12	24	36	48	60	72	84	96	108	l	
L	l^2	144	288	432	576	720	864	1008	1152	1296	l^2	*L*
	m	13	26	39	52	65	78	91	104	117	m	
M	m^2	169	338	507	676	845	1014	1183	1352	1521	m^2	*M*
	n	14	28	42	56	70	84	98	112	126	n	
N	n^2	196	392	588	784	980	1176	1372	1568	1764	n^2	*N*
	o	15	30	45	60	75	90	105	120	135	o	
O	o^2	225	450	675	900	1125	1350	1575	1800	2025	o^2	*O*
	p	16	32	48	64	80	96	112	128	144	p	
P	p^2	256	512	768	1024	1280	1536	1792	2048	2304	p^2 j	*P*
	q	17	34	51	68	85	102	119	136	153	q	
Q	q^2	289	578	867	1156	1445	1734	2023	2312	2601	q^2	*Q*
	r	18	36	54	72	90	108	126	144	162	r	
R	r^2	324	648	972	1296	1620	1944	2268	2592	2916	r^2	*R*
	s	19	38	57	76	95	114	133	152	171	s	
S	s^2	361	722	1083	1444	1805	2166	2527	2888	3249	s^2	*S*
Fr.		1	2	3	4	5	6	7	8	9	Fr.	

by use of the Job Analysis form. In using this form, the labeled windows in the left-hand column of each of the two sections are to be filled out first by merely copying into them the sums already determined and entered in the correspondingly labeled windows. Thereupon, the reduction of the formula is merely a matter of blindly following out the directions of, "add," "subtract," "multiply," etc., writing the sums, remainders, and products in the designated windows in turn. The three quantities, L, H and K, enclosed by a double rectangle, are the quantities which, when solved by slide rule in the second reduction of the skeleton formula, yield r. The slide rule is so efficient in this last step that it is not advisable to make out job analysis steps involving extraction of the square root.

In summary, this method of solving r simply is: Find vertical, horizontal and diagonal marginal frequencies, adding the corresponding lettered table products found in Table I. to obtain the lettered window sums which enter into the skeleton formula.

To find the average of the X-variable, or M_X: substitute the proper window quantities in the skeleton formula for M_X and solve; *the answer is in terms of table steps.* The resulting table steps must be interpolated to find the value of the average in terms of the X-variable scores. Thus, in Fig. 1, $M_X = 4.399$ table steps. Now the *fourth* table step in the X-variable has the *face-value* of 16.0; and .399 of a table step, where the class interval, $I_x = 3$, is $.399 \times 3 = 1.197$. Or, the true average of the X-variable is $16.0 + 1.197 = 17.197$. Similary, the average of the Y-variable is 7.674 table steps of the Y-variable, which interpolated gives the true average of the Y-variable, which is 5.674,($I_y = 1$).

The formula for the standard deviation is:

$$\sigma_X = I_X \sqrt{\frac{N\Sigma X^2 - (\Sigma X)^2}{N^2}} = I_X \sqrt{\frac{H}{N^2}}. \qquad (5)$$

Where, I_X is the class interval of the X-variable. Note that H is found in the reduction of the formula for r and

need not be recalculated. The standard deviation of the Y-variable is found by substituting Y for X in formula (5). The magnitudes of I_X and I_Y, the class intervals, do not enter into the computation of r; they are always to be made as small as the data will permit in order to reduce the grouping effect which occurs whenever data are grouped into coarser classes.

In practice it has been found that the only operation at all likely to result in errors is the counting of the diagonal frequencies. This may be partially obviated by use of a serrated edge. A very effective check, not only of the counting of the diagonal frequencies but also of the numerical work of the whole table, lies in the fact that the sum of the quantities $(A + B - C)$, when simplified in the skeleton formula, *must be an even number.* This follows from a consideration of the fact that ΣXY in equation (3) is always an integral number; therefore, $\frac{1}{2}(A + B - C)$ must be an integral number, but this is only possible when $(A + B - C)$ is an even number. If then a single error is made in either ΣX^2, ΣY^2 or $\Sigma(X - Y)^2$, it will very likely make $(A + B - C)$ an odd number, which odd number would always be a certain indication that an error had been made. The only safe method, of course, is to recheck every operation as is customary in all statistical work. With this method, intelligent clerical workers have been found capable of solving correlations with as much accuracy as trained statisticians. The total time required to solve a correlation is greatly reduced over that required by previous methods; while, with a single checking of all operations, errors in the final r almost never occur. Since the reduced numerator, L, and the quantities, H and K, are always integral numbers, it follows that the final value of r is never influenced by the extent to which the previous decimals, used in other methods, may have been carried out. The final operation is the only one in which decimals enter.

The speed of the plotting, and also its accuracy, may be increased by the use of the plotting device described below, to be used with the printed correlation sheets described above.

A Correlation Plotting Device.—In efficiency, the combination of printed sheet and plotting machine has been found through extensive try-out to yield Pearson correlation coefficients in from one-third to one-fourth of the time taken by other methods. In point of speed, it has been found possible to plot consistently twenty paired measures per minute with this device. The principle is quite general and will be useful in all cases where it may be required to locate quickly any desired compartment of a contingency table by means of its coördinates, as in reading products in the body of a large multiplication table where the two factors are printed as coördinates along the two edges.

The essential parts of this machine are a framework of wood, *A*, bearing a transparent celluloid stationary runner, *B;* a device for holding coördinate paper ($\frac{1}{4}$-inch squares) represented in the picture by the knobs, *C* and *D*; and a movable slide, *E*, on which the printed plotting paper may be fastened with thumb tacks.

In use, the printed correlation paper is tacked to the slide, *E*. A strip of $\frac{1}{4}$-inch coördinate paper is fastened to the edge of the stationary runner by inserting the tips of the coördinate paper strip under the washers found under *C* and *D* and tightening these knobs. The classes of the *Y*-variable are entered on this strip, while the classes of the *X*-variable are entered along the top of the printed sheet in their usual space. The operator manipulates the machine while the teller reads to him the paired measures, reading first the *X*-measure and then the *Y*-measure. The operator holds the slide, *E*, with his left hand. As the teller calls out to him, say 16, the operator moves the slide and with it the printed sheet until the 16-column of the *X*-variable is the first column visible to the right of the edge of the celluloid runner and paper slip, as in Fig. 3. He does this almost instantly by watching only the *X*-classes as they disappear beneath the paper strip, so that, by the time the teller has called the value of the second or *Y*-measure say 8, the operator is in position with his right hand to make a pencil mark tally along the edge of the paper strip

in that compartment which is directly beside 8 of the paper strip. This device is thus one for bearing the marginal frequencies of the *Y*-variable into the body of the table to secure accurate and speedy plotting; its psychological advantage being that the operator need give attention to but one of the coördinates at a time. There is almost no likelihood of error in the plotting if the operator calls back to the teller the two measures as heard and is checked by the teller.

By use of the serrated heavily inked-in diagonal boxes on the celluloid runner at *F*, it is easy to count the frequencies in any diagonal row without confusing them with the frequencies of any other diagonal row. Error in entering the diagonal sums in the "Diagonal Frequency" row is made mechanically impossible by having accessible only the one cut-out window, *G*, of that diagonal row whose frequency is being counted by the aid of the serrated boxes. This window, *G*, is so aligned with the last square at the top of the diagonal row as to be open only above the proper entry space of the diagonal row being counted.[1]

[1] The correlation sheets and table of products of deviation steps and their squares by frequencies may be obtained from the author, Institute of Educational Research, Teachers College. The correlation sheets have recently been revised as a result of two years' daily use in research bureau grading and testing work. After plotting, fifteen minutes is more than ample time for the solution of a correlation such as that shown in Fig. 1.

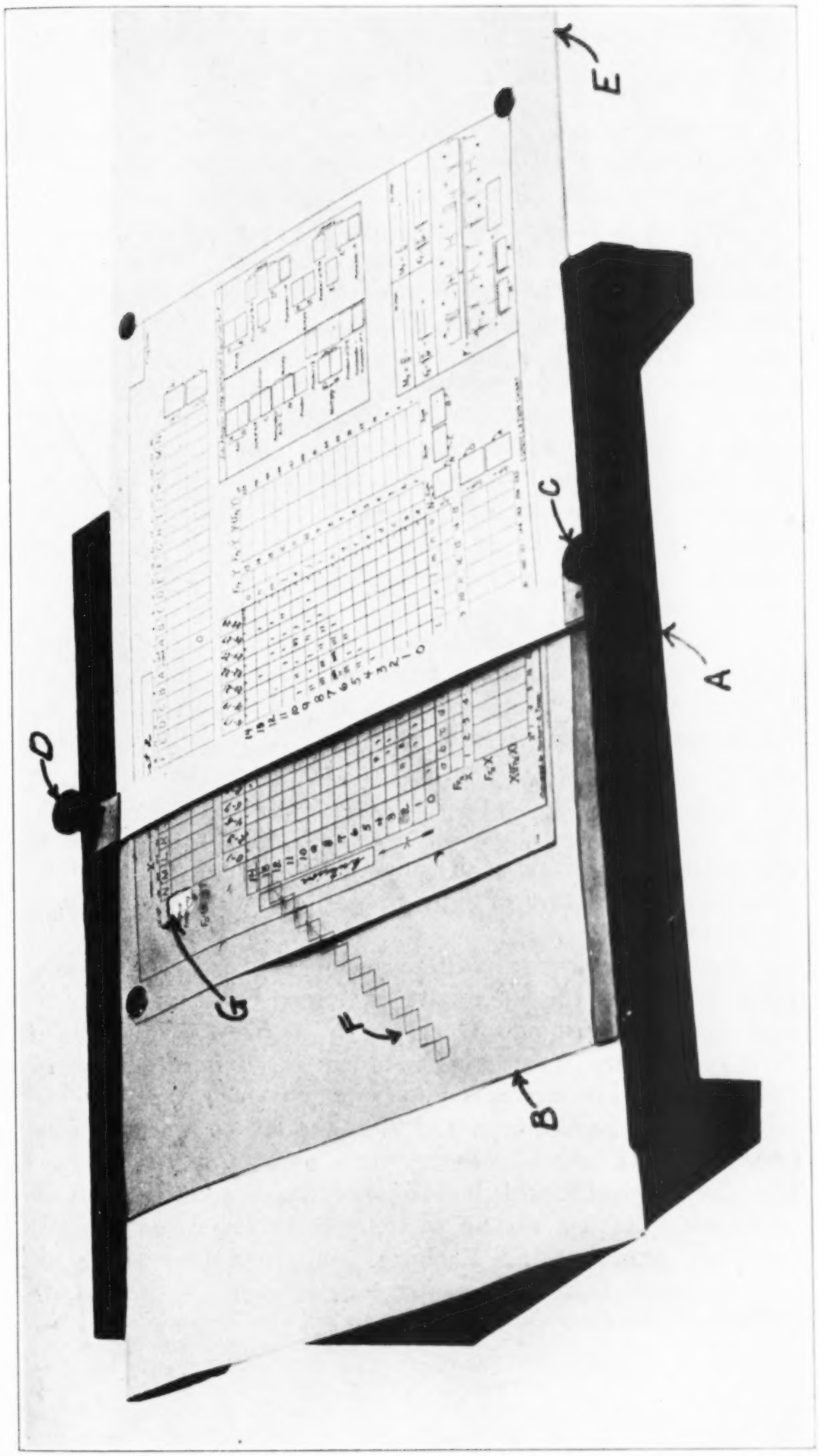

FIG. 3. A correlation plotting device

THE RÔLE OF SYNÆSTHESIA IN LEARNING

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Introduction.—A preliminary analysis of a case of synæsthesia by means of the introspective method clearly indicated that it was worth while to undertake several intensive studies of the phenomena first, for the reason that detailed introspective descriptions even from one trained synæsthetic reagent seemed to throw considerable light upon the nature and functioning of synæsthesis itself and upon several systematic problems the status of which seems to be in doubt as far as experimental results are concerned. Secondly, since our synæsthetic reagent is blind and since we were able to check his introspections against a second blind reagent who is asynæsthetic,[1] it seemed worth while to contribute indirectly to the literature on the psychology of the blind.

The purpose of this particular investigation was to ascertain the value and functioning of synæsthetic processes in learning and to draw such conclusions as might be possible regarding the nature of synæsthesis itself from a functional point of view.

Method, Apparatus and Observers.—Observer *A* is a graduate student at the University of Oregon with four years of introspective training. Observer *B* is likewise a trained introspector and was a major student of advanced standing at the time his introspections were obtained. *A* lost his sight at the age of eleven and *B* at the age of nine. *B* was employed as a 'check' reagent.

The material for this investigation consisted of two sets of nonsense syllables, one for tactual presentation and one for auditory presentation. Each set contained four series of

[1] The term 'asynæsthetic' was suggested to the senior author by Dr. Edwin G. Boring to designate a person's mental equipment which is not synæsthetic.

ten syllables each. The syllables for tactual presentation were punched by a Braille machine on rectangular pieces of tag-board 5 × 10 centimeters in size. These cards were placed on the table in front of the reagent. After he inspected the first card tactual fashion it was removed by the experimenter while the reagent lifted his hand and arm for an interval of three seconds. By the end of this interval a new card had been substituted and as the reagent lowered his hand he found his fingers in the correct position to begin reading the next syllable. An interval of six seconds was given between series presentations. A series was considered learned when the reagent was able to anticipate the syllables correctly. After the learning, the reagent recited the syllables, spelling each one, and then gave as complete an introspection as possible upon the learning and upon the immediate recall. Twenty-four hours after the original learning the reagent was asked to recall the syllables and to introspect on this delayed recall.

In the auditory presentations the experimenter read the syllables as distinctly as possible, without spelling the letters, and at three-second intervals, allowing six seconds between series presentations. Introspections were obtained after an immediate and after a twenty-four-hour delayed recall.

The learning was done throughout under optimal laboratory conditions. A second series of syllables was not learned until the preceding series had been recalled for the last time. Our rather slow presentation was a feature of experimentation introduced in order to enable the reagent to give more detailed introspective descriptions of his learning than would have been possible if he had felt hurried. We were not interested in the learning process *per se*.

Typical Introspective Data

Our introspections were so long and detailed, some of which covered four or five typewritten pages, that it is here impossible to present more than one complete introspection from each reagent; but the reader will be able to grasp some-

thing of the great detail into which the observers carried their introspective descriptions and will readily understand why it has been possible to obtain results of a fairly elaborate character.

1. *Observer B.* [Parentheses indicate the reagent's interpretations of his own mental processes after they had taken place. Brackets indicate comments inserted by the editors. Each introspection is numbered for the purpose of reference.]

"Was aware of the task in terms of kinæsthetic tensions centered about my eyes, brows, shoulders, left arm and hand, together with focal auditory perceptions of the experimenter's instructions and incipient tactual and motor imagery of masses of points on a dimly localized tag-board beneath my fingers. For an instant there was an entire exclusion of other processes. (These experiences meant to me both an attitude of acceptance and of expectation.) As the series was presented I was first conscious of blunt tactual sensations and of finger movements. Then these vague points became grouped into spacial arrangements which latter constituted my tactual perceptions of the letters. As the grouping took place I was less conscious of the individual points, and became aware of a broadening of the scope of tactual attention in which all of the points of a given letter stood out with approximately equal distinctness. At the final stage of a perception that part of a letter at which a point is missing stood out in focal consciousness, or the outstanding feature was a 'bar' made by two or more points in a line and extending in a certain direction—horizontal, vertical, oblique down and to the left, or what not. At times the length of the bar was the focal feature here, and at other times the direction of the bar was the focal feature. In still other instances the outstanding feature of the perception finally became an angle formed by a group of points. For example my perception of 'c' in one of the syllables consisted of a right angle which opened to the left and whose apex was pointing to the right. In 'd' the right angle opens to the left but the apex points upward and to the right. These features stood out in terms of tactual and

kinæsthetic imagery. The awareness of an angle consisted first of a combined tactual-kinæsthetic perception of the lower end or side; the perception always began at the bottom and developed upward and to the right in the direction of finger movement. There then developed incipient finger and arm movements of tracing the right angle. In letters like 'm' and 'p,' which if solid would make a similar angle kinæsthetic imagery, appeared with the movement longer on one side. The perception of each letter also involved incipient tactual-motor imagery of finger and arm movements having to do with punching these letters by the hand method of stylus and slate. This imagery was always more distinct in such letters as did not appear in the context for some little time."

"During the process of learning each letter lingered in consciousness momentarily, followed by vocal-motor imagery. As the vocal-motor imagery developed in each instance the tactual-motor features began to disappear. Consciousness of any syllable as a whole was entirely vocal-motor-auditory. During the intervals between presentations I was engaged in repeating the preceding syllables vocal-motor fashion. I noticed that in retaining the syllables the last feature of the tactual-kinæsthetic perception to disappear was invariably a single, dominating, incipient finger and arm movement. As the presentations continued I found myself trying to anticipate the syllables, using auditory-vocal-motor imagery wherever possible. This method proved more efficient because tactual-kinæsthetic imagery involved the details of three letters while the former imagery involved a simple sound or incipient throat movement. Only when I failed to anticipate a syllable in vocal-motor fashion did I find myself resorting to the slower method of using tactual-motor imagery. I learned the first and last syllables at the outset and the middle ones last."

"During the immediate recall I was first aware of the 'bih' in terms of auditory imagery in rising inflection as if I were about to ask the question 'How do you pronounce it?' As the vocal-motor-auditory imagery developed there also ap-

peared rather definite tactual-motor imagery of the syllable in which latter imagery the individual letters stood out prominently but only for a brief instant. There then occurred a schematic grouping of the syllables in terms of incipient movements of my shoulders as if throwing the subject matter of the series into separated spaces; and with each rhythmic emphasis in the motor tendencies I had the bare beginnings of auditory imagery of the syllables themselves. This schematic grouping arranged the first four syllables into one group, the next four into a second group and the remaining two in a third group. In anticipating the syllables, vocal-motor-auditory fashion, this schematic kinæsthesis was intensified at the beginning of each group. The second, third, and fourth syllables appeared in vocal-motor imagery, with no tactual-motor tendencies to spell out the letters until I spelled them for the experimenter. Fleeting and schematic imagery of letters came in tactual-motor fashion wherever there was difficulty in recalling the syllables." [Six presentations were required for the learning and the observer recalled the syllables correctly save for one letter in one syllable.]

2. Delayed recall: "First there appeared a diffused motor consciousness of strains about the brows, throat and chest; motor and tactual imagery appeared of my arms outstretched before me and of making movements of investigating Braille syllables. The first syllable came readily in vocal-motor imagery (suggested by the tactual-motor attitude just described). There was a slight tendency to translate the 'b' of 'bih' into tactual-motor imagery. The three syllables which followed came in auditory-vocal-motor imagery and with very little effort. As I recalled the fourth there first came a schematic visual-kinæsthetic image of a printed 'L'; no paper was visible in this image and no background save the 'nothingness' which is always associated with my visual imagery. The fifth syllable was hard to recall. At first I had 'vez' in auditory imagery which I found myself at once correcting to 'veh,' tactual-motor fashion. The antecedent of this correction consisted of developing tensions about the forehead

and trunk which grew more intense as my attention began to shift toward the act of anticipating the next syllable. There was kinæsthetic imagery of jerking my arm back; breathing seemed to be checked momentarily, with tensed diaphragm and a vigorous vocal-motor-auditory: 'No.' The next syllable, 'pog,' appeared in auditory vocal-motor imagery, together with incipient tendencies to vocalize it before I was certain that it was correct. Certainty here seemed to consist of the persistence of the auditory-vocal-motor imagery of the syllable, together with a developing tactual-motor image of the three letters and a tendency to smile. Then I paused; sudden tensions developed about the forehead, trunk, and especially in the jaws and throat; there came fleeting auditory imagery: 'What next?' I had tendencies to move my arm and hand as if feeling of letters (this together with the tensions constituted an effort to recall the next syllable.) Then I had tactual imagery of the laboratory table, cards, chair, and auditory imagery of the experimenter's voice. (These latter constituted a consciousness of the task.) Then I found myself exclaiming vocal-motor fashion, 'Oh,' as 'double U' appeared in vocal-motor-auditory imagery. Then the syllable 'nuz' suddenly appeared and I at once found myself vocalizing it. The remainder of the series came easily and in auditory-vocal-motor imagery."

3. *Observer A.* [Syllables were dop, jan, vum, qoh, qez, pif, xap, loy, pef, hov and were thus arranged in a series for the purpose of watching the behavior of synæsthetic imagery.]

"I first went through the series with the intent of becoming generally familiar with the syllables, and of constructing a pronunciation for them or a name for each. I grouped the first three together in terms of vocal-motor-auditory imagery, thus, 'dop-jan-vum.' I paid no attention to the tactual-kinæsthetic elements in the learning or in the perceptions of the letters. As fast as I inspected each syllable the appropriate synæsthetic visual image appeared at my finger tips, the coloring and brightness of the imagery being determined by the letter. When I then found myself vocalizing the syllable,

the syllable itself tended to take on the color of the initial letter. As my attention shifted from the procedure of inspecting the letters, tactual-kinæsthetic fashion, the visual imagery which at all times remained dominant in consciousness shifted to the center of my field of vision. Throughout, the tactual-motor processes were dim, vague, indescribable experiences of which I know nothing except in terms of their visual associates. [In other words the former were cues for the appearance of the latter.] It was not until the third repetition that I was able to anticipate any more than the first three syllables. My learning procedure consisted chiefly of visualizing the color for each syllable in a schema. The first three syllables assumed their place in a straight line to the left in the schema, and along with this there took place auditory-vocal-motor imagery of them. The remaining syllables were learned when I could fix a place for them in this visual schema. The fourth syllable to be thus placed in the schema was the eighth, whose color was brighter than its neighbors; this syllable occupied an elevated position in the form and considerably to the right of the first three. Between them and to the left of the eighth were spaces of neutral gray into which I later fitted the remaining syllables. After the first four or five presentations I changed my *Aufgabe* from that of retaining to that of anticipating the syllables and my method, as before, was almost entirely visual."

"As each syllable was inspected tactual-motor fashion my attention was centered visually upon the tips of my fingers; with a certain amount of finger-movement colors began to appear at my finger tips; these colors were my awareness of the letters as such; just as soon as these colors began to develop I shifted my line of regard to the center of a visual field extended out before me in space and there tried to visualize the syllable in color."

"When I centered my attention upon one section of the form, it only was clearly 'seen'; in indirect vision I could 'see' adjacent sections. The brighter or more persisting colors of these sections tended to draw attention away from

the section upon which I was focusing my attention at the time. This often resulted in confusion. In the process of trying to anticipate the syllables it frequently happened that more than one color would thus attract my attention before I succeeded in clarifying a dim section in the form. I also found myself confusing colors for individual letters with colors for entire syllables. I would then have to wait for the next tactual-motor presentation in order to ascertain which color stood for a letter and which for a syllable. I had a great deal of trouble with 'pif.' The color for this syllable persistently appeared out of order."

"As the form developed it became stable and the sections standing for individual syllables were definitely differentiated. The first three syllables formed a straight line of three colors to the left; the 4th, 5th and 6th assumed a position, in colors, along a downward slant toward the right, beginning where the third syllable left off. The 7th was learned last and came to occupy a dip in the form below the others; the 8th appeared as a high crest to the right of the dip and the 9th and 10th assumed a slanting position at the right end."

"I announced that the learning was complete as soon as I was able to follow along this visual form just ahead of the tactual-motor presentation of the syllables. I fixated each section of the form and translated the color vocal-motor fashion. It was then verified by a brightening process which the colors underwent when I inspected the syllables with my fingers."

"In the immediate recall I found my visual attention centered upon the left end of this visual schema. The appearance of the first three syllables in a straight line meant to me that I had learned these together and with ease; they were dominantly grayish-green in color, shading toward a lighter tint at the extreme left; the lighter left end told me at once that the syllable began with 'd.' The visualized 'd' suggested at once the syllable 'dop,' which in turn suggested the next two syllables with no necessity of translating, consciously, from the visual schema. But as I vocalized these

syllables the colors of this section of the schema brightened. I then found myself fixating the downward slant of the form; the first section of this region was colored by the letter 'q'; the second was colored by the 'z' sound in the syllable, and the third was colored by the 'x.' I fixated my attention first upon one of these colors and then upon the other. Then I translated these colors into their appropriate letter-sounds and subsequently, by means of a trial and error method, pronouncing different sounds to myself, I built up the syllables, 'qoh,' 'qez' and 'xap.' The final recall came in auditory-verbal imagery together with a brightening of the colors in the form. In turn, the 'pif' and 'loy' stood out in their own distinct colors; then at the last, 'pef' and 'hov.' In no instance was a syllable recalled first in vocal-motor fashion. Each recall was constructed rather laboriously from the verbal suggestions which came from the localized colors of the form."

4. Delayed recall: "The intent to recall the syllables of the day before led at once to colored visual imagery of the form before described. I found myself fixating the extreme left end and then moved my line of regard to the right over the first three sections which formed a straight line. This triple section was a dark, grayish-green, but lighter at the left end. I found myself saying 'd' in vocal-motor imagery as I fixated the lighter portion at the left and then, suddenly, there came the vocal-motor-auditory imagery of 'dop,' 'jan' and 'vum.' Next, moving my line of regard downward over the oblique slant which marked the next large section in the form, I noticed that the first letter of each of the next two syllables was 'q,' because the color of the form was a dark, brownish-green. As I vocalized the 'q' there at once followed the vocal-motor 'ez' together with the colors for 'e' and 'z' which appeared in the lower half of my field of vision and floated upward, fitting into their appropriate places in the form. I then found myself repeating 'q' again in vocal-motor imagery; then I had 'o' both in vocal-motor and visual imagery, the color for the 'o' taking its place next to

the 'q' in the form. Next the syllable 'pif' came easily for I could see all three letters standing out in terms of their colors. I then saw the 7th syllable as a very dark, brown section in the form but I could get no verbal imagery from looking at this color. Next my visual attention was claimed by 'loy' which stood out as the high crest or shoulder in the form; this section was dominated by the smoky blue for 'l.'"

"I now have the missing syllable—it is 'xap.' The first hint of it came in terms of the light straw yellow of the letter 'a'; then came the poorly saturated reddish-brown, followed by the 'p' in simultaneous vocal-motor-visual imagery. These colors appeared in their proper sections in the form."

"I next turned my attention to the right end of the form where I saw distinctly the colors for 'pef' and for another syllable which I could not then translate. After a few seconds the syllable 'hoy' came to me, later corrected to 'hov.' In the last section of the form the dominant color stood for 'o.' For some time I fixated that small patch of color in the form, moving my line of regard over the neutral gray surroundings, hoping other colors would appear, when I found myself vocalizing 'v,' which in turn suggested the 'h.' These latter came in combined vocal-motor-auditory and visual imagery."

"(In my recall I at first reversed the order of 'qoh' and 'qez.' This was due to the fact that both syllables began with the same letter and looked just alike in the form, for in these two instances the colors of the section were determined by the initial letter of the syllable. There was no criterion by which I could at first tell which syllable was first and which second. I have no such difficulty in cases where the three letters stand out in colors in the form.)"

Summary of Data from Observer *B*

B's procedure in the learning consisted first of perceiving the individual letters of each syllable; secondly of grouping these letters into a word, vocal-motor and vocal-motor-auditory fashion; thirdly, of repeating these syllables over and over again, holding them in consciousness as best he could

in this fashion while he inspected two or more subsequent syllables; fourth, of anticipating the syllables in terms of vocal-motor imagery.

It is interesting to note that the dominating features of *B's* tactual perceptions were invariably (1) motor imagery of angles or (2) motor imagery of punching the point letters (3) verbal imagery. These processes terminated any given act of perceiving and identified the letter.

As learning progressed, *B* tended to rely more and more upon vocal-motor-auditory imagery, resorting to tactual-motor imagery only when in difficulty. Tactual-motor imagery always turned out to be a laborious method of retaining the syllables for the reason that each letter had to be represented. By means of a motor schema, involving incipient shoulder movements, *B* grouped the ten syllables into 4, 4, and 2.

This grouping was rather prominent during the immediate recall. Here *B* invariably resorted to vocal-motor-auditory imagery first, and if one syllable failed to suggest the next he became conscious of the *Aufgabe* in terms of muscular strain, or of tactual-motor imagery of the table, the cards or of previous syllables. Tactual-motor imagery of syllables functioned only when auditory-vocal-motor imagery was obscure or lacking.

In the delayed recall the syllables appeared both in auditory-vocal-motor and in tactual-motor fashion. Here the latter processes were somewhat more pronounced than in the immediate recall and functioned both to supplement incomplete auditory-vocal-motor imagery and to correct wrong auditory-vocal-motor processes. The cues which aroused the imagery of the various syllables were not always obvious. The *Aufgabe* to recall readily sufficed to suggest the first syllables of the series. Usually the next three or four syllables came readily in auditory-vocal-motor fashion. Toward the latter part of the recall the syllables appeared less easily and there were frequent returns to a consciousness of the task. As far as one syllable was recalled by means of observable

cues these cues consisted wholly of auditory, tactual and kinæsthetic processes.

B learned the syllables, on the average, in six repetitions of the series.

Summary of Results from Observer *A*

A's procedure in the learning was as follows: He first inspected each syllable in tactual-motor fashion but paid no attention either to the tactual or to the motor elements as such. As soon as the points of each letter were felt, there appeared visual imagery at his finger tips; this imagery became colored as the points of the letters became grouped into characteristic formations. In other words *A* invariably perceived and recognized the letters in terms of colors which took on various shapes and sizes according to the letter-meanings. Secondly, he constructed auditory-verbal imagery of each syllable, together with a color for the syllable as a whole. At times the initial letter of the syllable determined the color, and at times each letter was represented. In other instances the color of the syllable was dominated by the vowel sound. Thirdly, he retained these syllables by fixing these colors in certain positions in a visualized schema. This process was involuntary at the outset but at once became the tool of a voluntary effort to remember the syllables. Fourth, he used this schema in anticipating the syllables in the later presentations of any series. Meanwhile tactual-motor perceptions and auditory-vocal-motor imagery were used to fill gaps in this form, to correct erroneous colors or to eliminate confusions in the colors.

The immediate recall consisted chiefly of translating the colors of the form into vocal-motor imagery. Where a syllable was represented by only one color *A* was forced to resort to vocal-motor expedients and to a trial-and-error method of completing the syllable. Where the appropriate color failed to appear and to assume its correct position in the form, whether this color stood for an initial letter or a vowel, or whether it represented an entire syllable in terms of

its initial letter, *A* was forced to try such indirect methods or to 'wait' until the appropriate colors appeared in consciousness. A color which occupied sufficient space in the form to cover the positions for three letters stood for an entire syllable. On the other hand certain syllables were represented by three colors in which case the recall was easy.

Colors which were not present in the form at the outset of the recall invariably appeared in the lower half of *A's* field of vision, below the form, and migrated to their appropriate places in the schema itself. Auditory-verbal imagery always brightened the colors and made them more persistent.

The delayed recall resembled the immediate recall in most respects. The colors of the form were as a rule quite as vivid as on the preceding day. Here, however, the process of translating some of the syllables was more difficult owing to the fact that the associations between a single color and the remaining letters of the syllable had been lost temporarily. For the time being no amount of effort resulted in obtaining further cues. In such instances it invariably turned out that the color was not faithful to the syllable or letter, that a certain combination of letters in a particular word caused *A* to visualize a foreign or unrecognizable mixture of colors, or perhaps a certain color had faded or had otherwise changed in such fashion as would lead it to suggest either more than one letter or the wrong letter.

A required from 6–9 presentations in learning the syllables. *B* learned them more rapidly. This fact is explained on several grounds. (1) In *A's* case the letters thus grouped into syllables in meaningless fashion tended to produce detached or dissociated colors which did not 'hang together.' As a result his consciousness at times became flooded with 'floating' colors whose combinations were unstable. This difficulty arose even during the process of learning itself and was the source of not a little confusion. (2) The colors for syllables were often dominated by the color for one letter, thus making it necessary to resort to such expedients as tactual-motor or auditory-vocal-motor imagery in retaining

the other letters; but as fast as *A* could fill out the remainder of the syllable in this fashion, the dominating color would persist in blotting out the less stable colors of the remaining letters. (3) In the act of anticipating the syllables many errors were made which had to be corrected. These errors were due to tendencies to anticipate the brighter or more stable colors out of their order in the series. (4) Attempts to fill in gaps in his form or to anticipate syllables in auditory-vocal-motor imagery inevitably dragged into consciousness additional arrays of colors which either had to be differentiated from the correct colors, in case of auditory-vocal-motor guesses, or which had to be ignored. Thus *A* was prevented from employing auditory-vocal-motor imagery in the learning unless he were certain that this imagery was correct. This difficulty was due, in general, to the fact that *A* cannot think letters, verbal fashion, in the absence of colors.

Observers *A* and *B* Compared

1. Tactual and motor images other than auditory-vocal-motor were employed by *B* in the process of perceiving letters, in retaining letters whose sounds had not become familiar, and in retaining syllables whose sounds were difficult to pronounce. This same imagery was used under similar circumstances in anticipating and in recalling the syllables. In *A's* case such imagery functioned only as a stepping stone in the arousal of colors and in no instance was it attended to as such.

2. Kinæsthetic imagery and incipient movement were employed by *B* in grouping the syllables into a schema. This grouping was done by *A* in terms of a visual schema in which each syllable assumed a definite place and took on a definite coloration.

3. *B* used auditory-vocal-motor imagery in retaining, in anticipating and in recalling the syllables. This type of imagery dominated throughout *B's* procedure. *A* used auditory-vocal-motor imagery only in connection with visual synæsthetic colors, either in an effort to arouse colors, to strengthen them, or to translate them into language.

4. Visual imagery appeared only rarely in *B's* case and was never used in the learning. In *A's* case visual imagery assumed a wide variety of rôles: (1) As synæsthetic features of his 'tactual-motor' perceptions of the letters, in which cases the colors identified the letters; (2) as synæsthetic features of vocal-motor-auditory imagery of syllables or letters; (3) as detached symbols for letters or for syllables in the absence of other processes; (4) as sections in a schema or form, standing for a syllable or an entire series of syllables; (5) as cues by means of which syllables or letters were anticipated; (6) as cues by means of which syllables or letters were retained and recalled.

Summary of Results from Auditory Presentations

B's procedure in learning nonsense syllables with an auditory presentation was confined wholly to the use of auditory-vocal-motor imagery. Upon perceiving the syllables he translated them into auditory-vocal-motor imagery and repeated them over and over again, holding as many syllables in consciousness as possible before the next syllable was given. This method was soon changed to that of anticipating the syllables, auditory-vocal-motor fashion. Whenever one syllable failed to suggest another he found himself recalling syllables which came earlier in the series or anticipating in advance such syllables as came later in the series. If these expedients failed he became absorbed momentarily in masses of motor imagery and strains which constituted effort and impatience.

A's synæsthetic phenomena began to function at the outset in learning syllables by the auditory method. Auditory perceptions consisted in large measure of flashes of brightness and of color, determined either by the initial letter of a syllable or by some other prominently sounding letter. These flashes of color ultimately became fixed in a form as in the case of tactual presentation. *A's* visual imagery became fixed by repetition as did *B's* auditory-vocal-motor imagery.

As before, those syllables were learned first whose colors were brightest and the symbolic representation of such syl-

lables appeared as shoulders or peaks in the schema. Anticipation of syllables and the recalls took place as in the previous experiment. When this observer was about to recall any given set of syllables he was utterly lost unless the colors appeared in connection with the intent to recall. In such instances in which the colors were stable *A* found it quite as easy to repeat the syllables backwards as it was to repeat them in the order learned. On the other hand, his method of employing colors caused him numerous difficulties.

We have already mentioned several reasons for this. In the present experiment other difficulties came to light. (1) The color for the initial letter of a nonsense syllable may not be as definite, as well saturated or exactly the same quality as the color which ordinarily stands for that letter for the reason that the letter itself represents an entire syllable. Certain letters are known not only by means of their hue or brightness but by means of their shape. In case a letter represents an entire syllable its shape is changed to cover, in the schema, sufficient space to be occupied by three letters. (2) The colors for letters are influenced by the setting in which those letters appear, and by the amount of emphasis which the letter happens to receive in any particular context. (3) Certain letters take on varying colors or shades of brightness according to the different situations in which they function.

On the whole, however, the colors employed by *A* in these investigations agree with the colors for these letters, reported two and three years previous. But any variations in colors so far discovered in our investigations clearly point to the fact that where meanings remain the same so do the colors and where meanings change, so do the colors.

In the absence of a color or definite brightness, *A's* implicit *Aufgabe* to recall a given syllable consists of visual fixation upon a vacant section in the form. First his line of regard is rigidly centered upon the extreme left-hand portion or edge of this vacant section and is then moved across toward the right.

This act may be repeated several times. Meanwhile the entire form tends to split up, requiring considerable eye-movement and vocalization to keep it intact and in the center of the field of vision. Any fluctuation in shape or incipient change in color or brightness at once claims *A's* attention. Perhaps this incipient change is the forerunner of a definite color or brightness which leads to the desired verbal process and hence to the desired recall. Perhaps the vacant section in the form fails to 'fill in.' In either case the change comes of itself. Voluntary effort is invariably an indirect procedure consisting of motor-visual factors such as eye-strain, eye-movement, sudden motor-visual fixations upon changes of color and brightness in the form itself, strains in the throat, chest and arms.

On the whole, then, *A's* procedure in this experiment did not differ materially from his procedure in the tactual series other than in the method employed in arousing the original colors. In either case learning took place in terms of the manipulation of colors and these colors were determined by the letters and not by the mode of presentation. In both instances the colors were identical with those which symbolize the same letters in *A's* everyday mental life, with the exceptions above mentioned.

B's method in this experiment was likewise similar to his method in the previous experiment with the exception that, in the latter, tactual-motor processes figured in retaining, in anticipating and at times in recalling such syllables as failed to appear in auditory-vocal-motor fashion.

A comparison of *A's* performances with *B's* in this latter experiment confirms our results from the tactual presentations. In *B's* learning, one auditory-vocal-motor process led to another. These processes were his only cues. *A* had no tactual imagery. *A's* auditory-vocal-motor imagery was used only indirectly. In *A's* case colors were used at times as cues in arousing auditory-vocal-motor imagery and the latter was used as a frequent cue for the arousal of colors and for the strengthening of colors. There was no analogous

process in *B's* procedure unless it could be said that one auditory-vocal-motor image suggested the next and that the next in turn reinforced the first. At any rate, in *A's* case this mutual reinforcement or facilitation process which went on between colors and inner speech is a characteristic feature of his synæsthetic phenomena and a function which strikingly reminds us of reciprocal innervation.

In this facilitation process we find another characteristic of synæsthetic phenomena. Both the auditory-vocal-motor process and the visual image play the double but successive rôle of stimulus and response. For example, the appearance of a brown color in *A's* visual form sets off the vocal-motor image of 'm' whereupon the brown color itself becomes more stable and definite. On the other hand if a certain color fails to develop to that stage of definiteness which will enable the reagent to translate it into its appropriate vocal-motor associate he resorts to vocal-motor imagery of various letters in order to find the associate which will definitize the color for future use. At times *A* finds himself vocalizing in order to arouse a desired color. Here the auditory-vocal-motor process seems to possess a stimulus function and the color becomes the response. The transition from visual to vocal-motor image is the slower of the two and is a process of translating the visual symbol, now detached from its vocal-motor associate, into the vocal-motor process. The transition from vocal-motor to visual process is exceedingly rapid and consists only of a shift of attention from the vocal-motor to the visual feature. The former seems to 'drag in' the latter. The vocal-motor feature, however, is never definite in itself and is known to the reagent only in terms of the characteristic behavior of the visual associate. By this latter he can tell definitely when the former appears and disappears. The vocal-motor-auditory feature does not exist alone in consciousness; it is noticeable whenever the visual feature is present to interpret it. On the other hand the visual feature often stands alone in consciousness. Such detached visual associates float about in *A's* field of vision and are controlled

by eye-movement. By having recourse to the vocal-motor-visual combination the visual feature is rendered stable.

The two sorts of voluntary control differ in that arousing an auditory-vocal-motor process by way of the visual begins with a tentatively dissociated visual image while the act of recalling a visual image takes place at once with the recall of an auditory-vocal-motor process. The latter is never dissociated from the visual accompaniment, *i.e.*, it cannot stand alone in consciousness. The direction of *A's* attention as determined by the implicit purpose of the moment directs the order of appearance of verbal and visual process.

Summary and Conclusions

1. Synæsthetic phenomena appear throughout the learning, in *A's* case, as follows:

(*a*) in perceiving the letters and syllables;
(*b*) in retaining letters and syllables during the presentation of the series;
(*c*) in anticipating letters and syllables during the presentations;
(*d*) in immediate recall;
(*e*) in delayed recall.

2. Synæsthetic imagery functions in part as the content of self-imposed tasks. These tasks may be conscious or deliberate or they may be implied in the behavior of the reagent.

3. Synæsthetic visual imagery delays the process of learning owing to the fact (*a*) that a syllable is frequently represented only by the color of a dominant letter, (*b*) that auditory-vocal-motor guesses cannot be made without increasing the variability and complexity of this synæsthetic imagery, (*c*) that the visual associates become detached from their parent processes and fail to arouse the latter during recall, (*d*) that synæsthetic colorations vary in different situations and contexts.

4. *A's* learning has been checked in every respect against *B's* and throughout no functional differences are apparent. A comparison of the two observers shows that such differences

as are found between them are concerned only with contents.

B perceives letters tactual-motor fashion. Here the spacial grouping of letters develops in terms of bars and angles with the aid of kinæsthetic imagery and incipient movement. *A* perceives letters with the aid of synæsthetic visual imagery. Here tactual and motor factors always remain in an obscure and indefinable background.

B perceives syllables in terms of verbal imagery. *A* perceives them in terms of verbal processes plus synæsthetic visual imagery. Here, as well, the auditory-vocal-motor features remain in the background.

B perceives syllables directly in auditory fashion. *A* perceives the spoken syllables in terms of flashes of color and brightness.

The learning progressed in like fashion in both reagents as far as its functional aspects are concerned. Both were doing the same sorts of things throughout but where *B's* mental contents were tactual, motor, and auditory, *A's* were dominantly visual. The fact that *A* uses stereotyped visual imagery and the fact that he is synæsthetic resulted in certain difficulties of learning on the one hand and in a certain ease of recall on the other which were not characteristic of *B*; but these features of the learning turned out to be incidental rather than inherent in the learning process as such. They were due to the differences in mental contents between the two reagents and not to differences in basic mental functions. Such functions as attention, voluntary control, retention, anticipation, recall, association, the use of schema and the like took place in identical manner in the two reagents, barring incidental differences found in the behavior of differing mental contents.

5. *A's* synæsthetic phenomena are here identical in perceiving and in remembering, barring such changes as occur with changes in meaning.

6. We conclude that, in the process of learning, *A's* synæsthetic phenomena are normal functions whose contents,

alone, are unusual. These phenomena are as essential to his learning as processes of perceiving and recalling are essential to *B's* learning. Indeed, *A's* synæsthetic phenomena are his methods by which he perceives and recalls.

7. Synæsthetic phenomena are not confined to the realm of perception alone in *A's* case. They are quite as evident in his processes of thinking. They are throughout concerned with the development of meaning. In this case of learning meanings were confined to letters and to sounds.

8. Two sets of factors in the behavior of *A's* synæsthetic phenomena point to the view that synæsthesis is a form of conditioned reflex: (1) The parent tactual, motor or auditory-vocal-motor process acts upon the visual associate in a manner functionally resembling facilitation; (2) the colored associate is a stereotyped response to the parent process as a stimulus. The fact that the colored associate may come to function as a stimulus for the arousal of the parent process does not seem to militate against this view since the conditioned reflex as a type phenomenon need not be confined to the realm of external stimulus and explicit muscular response.

9. Voluntary control of a mental process in each reagent was an indirect process, *i.e.*, a given mental content was controlled indirectly by means of an antecedent sensory or ideational cue together with eye-movement or other incipient motor process.

LOCAL SIGNATURE AND SENSATIONAL EXTENSITY

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The various theories aiming to account for local signature may apparently all be classified under three heads. These are (1) the kinesthetic theory, (2) the sensory-complex theory, and (3) the sensory-element theory.

The kinesthetic theory is explained as follows by William McDougal:

> The process by which the axis of the eye is turned toward the optical image is probably a pure reflex of the spinal level. . . . When such a movement of the eye is made, a certain complex of kinesthetic sensations is excited. . . . Hence we may assume that the turning of the eyeball in its socket to any position excites the sense-organs of the socket and surrounding parts in such a way as to arouse a certain complex of kinesthetic sensations that is peculiar to each position, and that this complex of kinesthetic sensations is the primary form of the local sign. (Primer, p. 97.)

Against this kinesthetic basis of retinal local signature Charles S. Myers urges the following weighty objections:

> In cases of congenital blindness, the individual is at once after operation able to recognize differences in size and in form of images received by the retina. So instantly is a round object seen to differ from a triangular one, that the judgment is clearly independent of the training which would be needed before the eyes could be moved in a fashion orderly enough to follow the outlines of the object.
>
> Again, in certain cases of retinitis, where the elements in the affected region are abnormally crowded together or separated by inflammatory products, a local 'metamorphopsia,' or distortion of vision, is produced. It arises from the fact that the displaced retinal elements retain their normal local sign under these conditions. A line whose image falls on the affected area of the retina, appears bent or bowed out, according as the elements are unduly separated or contracted. Such distortion would surely be corrected in time if motor sensations were the basis of local signature. In point of fact, it is said to persist for months or even for years—indeed, as long, perhaps, as the pathological condition remains.
>
> Lastly, attention may be called to the fact that lines which subtend less than an angle of one minute can be spacially distinguished by the eye. If such discrimination depended for its origin on kinesthetic sensibility, then the delicacy of kinesthesis in the orbits must be almost incredibly greater than that in any other part of the body. (EXPERIMENTAL PSYCHOLOGY, p. 230.)

On the basis of these objections, Myers thinks "we can hardly avoid the conclusion that the local signature of the retina is innate, and that the basis of it is to be sought rather on the sensory than on the motor side of the retinal sensori-motor mechanism." A similar conclusion is probably true as regards the skin.

According to the sensory-complex theory the sensations received from the elemental end organs in the skin, from the end organs of the kinesthetic and visceral sensations, and from the separate rods and cones in the retina are all respectively alike, and the differences in local signs that we experience are all due to different combinations or complexes of these homogeneous elemental sensations.

According to the sensory-element theory, the elemental sensations received in the sense departments just mentioned are all slightly different, and specific locations on the body, within the body, and directions in space perceived visually, are learned by means of associations with these differences. The theory assumes that no two elemental skin, retinal, or organic sensations are really alike, and that each possesses the earmarks of the particular region of the body from which it comes. The difference is not caused merely by differences in the structures accessory to the receiving nerve ending, such as the texture of the skin and the proximity of bones, but is one that inheres in the sensation itself. This may, perhaps, be best understood by assuming that the sensory areas in the brain are made up of a point for point projection of the extended receiving areas of the skin, retinas, and internal structures. To have all touch sensations, for example, strictly alike in the touch quality, they should all theoretically be received by the same brain elements, and if the same brain elements could or did receive the touch sensations coming from all parts of the body, there is logically no reason why this receiving should not be done by one neurone. But with an extended tactual area in the brain it may easily be true that each tactual end organ has its own receiving point in the brain, and because of having its own brain localization

it may also well have its own psychical characteristics so that no two touch sensations are really alike, while they are nevertheless enough alike to be called tactual. What holds for touch sensations may hold also for visual and organic sensations. The point involved may be aided by an analogy. No two people are really alike—we can tell them all apart—yet they are sufficiently alike to be classed as people. Each person has his own 'local sign,' so to speak.

Granted that the arguments advanced by Myers are conclusive against the kinesthetic theory, the choice then lies between the other two. This choice must in the end be made on the basis of experimental and anatomical evidence.

The experiments that I am reporting in this paper all appear to point to the truth of the sensory-element theory. I performed experiments only upon the skin, stimulating the radial side of the forearm in four subjects with a Bloch instrument. The subject was touched with his eyes closed and was then asked to locate the touch with the point of a pencil, eyes open. The amount of error was measured in mm.

For readiness of comprehension the experiment may be divided into four series. In one series the stimulus was applied to a conspicuous vein and in another to a portion of the skin where no vein was in evidence. Furthermore, the stimuli were given in two degrees of intensity, namely 1 gr. and 10 gr. Twenty stimuli were used in each series, making a total of 80 for each subject. The results are summarized in the following table:

	Vein			Arm	
Subject	Pressure	Av. error	M. V.	Av. error	M. V.
A.....	1 gr.	8.5	4.7	14.5	6.5
	10 gr.	8.5	4.7	10.3	5.2
B.....	1 gr.	6.2	3.3	7.3	3.4
	10 gr.	6.2	2.8	6.8	3.5
C.....	1 gr.	9.3	4.2	12.7	6.1
	10 gr.	8.6	5.5	10.0	4.8
D.....	1 gr.	11.0	7.1	10.0	6.6
	10 gr.	8.0	4.6	17.0	$8.\overline{3}$

If the sensory-complex theory were true it would seem reasonable to expect that a strong stimulus, within certain limits, would enable more accurate localizations than a weak stimulus, but this is not the case. The advantage appears to be slightly in favor of the weak stimulus.

Again it would seem reasonable to expect that when the stimulus is applied to a vein, where the subcutaneous tissue is uniform, localization would be less accurate than when applied to other parts of the skin where the subcutaneous tissue is variable. But the reverse appears to be the case. In seven out of the eight cases localization was more accurate on the vein.

In a preliminary way I have experimented also with cold spots. I spent about three hours letting one of my students stimulate marked cold spots in my forearm. It proved somewhat difficult to get cold sensations unaccompanied by touch sensations, but many pure cold sensations were received. Localization was just as accurate as with touch sensations or as with cold and touch sensations combined.

All these results, it seems to me, point toward the truth of the sensation-element theory and away from the sensation-complex theory.

There is another argument against the complex theory. A complex is possible only on the assumption that the elements that go to make up the complex are different. With like elements, only a difference in intensity could be produced and that would be of no service in aiding localization. In the skin and the tissues underneath there may be a sufficient variety of sensations to give complexes, even if all cutaneous touch sensations were alike, but it is hard to see how this could be true in the retina. But if the complex does count in the skin, this should have come out in our experiments. The fact that localization is no less accurate with a weak stimulus than with a strong one, and the fact that it is more accurate on than off a vein count against the complex theory.

Granted inherent differences in sensations from different parts of the body and we have a clear basis for local signature;

indeed, such differences are local signs. Yet such differences of themselves do not give spacial position or direction; they are merely the ground on which such position or direction may be learned. The acquisition of space relations on the skin, for example, consists of learning the meaning of these minute differences in terms of visual and kinesthetic sensations. In acquiring the ideas of visual space it is necessary for the kinesthetic and skin sensations to become associated with the retinal signs.

Sensational extensity, as an elemental quality, becomes an entirely superfluous assumption. The awareness of differences in size on the skin or in the visual field are adequately explained as perceptual complexes. The end of a pencil stimulates many more touch end organs than the point and so arouses a different sensory complex which experience has taught us to mean a larger area.

The superfluous nature of the quality of extensity in sensation does not, of course, prove its non-existence. The arguments, however, that are advanced in support of extensity as an elemental quality are not sound. Titchener, for example, says:

> Sensations of color are spread out really into length and breadth; they appear as spacial extents. And this attribute of extent is part of their very constitution. Reduce the color to a pin point, and it still occupies space; think away the spacial attribute, and the sensation has disappeared with it. So with pressures; set the point of a stiff horse-hair lightly down upon the skin, and the sensation is extended, diffused over a mental area. Certain sensations, then, have extent; others, as odors and tones, show no trace of it. (Textbook, p. 54.)

Looked at from the objective, or logical, side, this argument appears unanswerable, but when it is looked at from the subjective, or psychological side, its unsoundness becomes clearly evident. Without the power of movement and without any other experiences whatsoever, the stimulation of one end organ either in the skin or in the retina would appear to the subject merely as a modification of consciousness, and there is no reason why it should have any more suggestion of extent than a sensation of smell or sound. Extent as we know it is an objective datum that acquires its objective

meaning through experience. Just because we cannot think of the external world without it does not make it an elemental quality of sensation. Any sensation coming from a single sense organ may still be absolutely innocent of it.

Another argument for the sensational nature of extensity that is frequently given is still more obviously fallacious. It is said that the fact that the congenitally blind can at once distinguish different shapes, such as circles and squares, when their sight has been restored by a surgical operation, proves that visual sensations have the innate quality of extent. These people seem to forget that a person when looking at a ball or a box has not only one, but many end organs in the retina stimulated, so that he bases his judgment, not on one, but on a complex of sensations. This complex *has* to be different for a circle from what it is for a square, and it is not at all surprising that a person even on the first trial can tell one from the other. There is no more reason why he should not be able to distinguish them than why he should not be able to tell one complex taste from another complex taste, or one complex sound from another complex sound. It is right here that the innate differences of the various single sensations, granted their existence, do their service. These should give a characteristic consciousness for each group or complex of sensations, which, when received from the skin or retina, is interpreted by the assistance of other experiences to mean certain definite spacial relations.

So far as the functioning of the mind is concerned, it makes no difference whether sensations have extensity or not, or whether some sensations have this quality and others do not. If they have it, it is an interesting fact, but that is all. Space perception, both visual and tactual, may develop perfectly well without it. Professor James is very insistent in the beginning of his chapter on space perception that all sensations have the inherent quality of extensity or voluminousness, but when later on in the chapter he explains how our actual and precise ideas of space are obtained he makes no use of this quality. Neither does any other writer make use of it.

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